AD/A-001 739

DYNAMIC LOADS AND STRUCTURAL CRITERIA STUDY

K. R. Spreuer, et al

Summa Corporation

Prepared for:

Army Air Mobility Research and Development Laboratory

September 1974

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Results of this program are immediately usable but also indicate that additional work is desirable to refine and verify the load factor distribution techniques.

This report has been reviewed by this Directorate and is considered to be technically sound.

The technical monitor for this contract was Mr. Arthur J. Gustafson, Technology Applications Division.

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: USAAMRDL-TR-74- 4
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): DYNAMIC LOADS AND STRUCTURAL CRITERIA STUDY
5. TYPE OF REPORT & PERIOD COVERED: Final 12-73 thru 5-74
6. PERFORMING ORG. REPORT NUMBER: 369-X-8040 (HH74-124)
7. AUTHOR(s): K. R. Spreuer, S. J. Snackenburg, G. D. Roeck
8. CONTRACT OR GRANT NUMBER(s): DAAJ02-74-C-0018
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Hughes Helicopters, Div. of Summa Corporation, Centinela & Teale Streets, Culver City, California 90300
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 1F162208AH9001
11. CONTROLLING OFFICE NAME AND ADDRESS: Eustis Directorate, U.S. Army Air Mobility Research & Development Laboratory (USAAMRDL), Fort Eustis, Virginia 23604
12. REPORT DATE: September 1974
13. NUMBER OF PAGES: 131
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office):
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Helicopters, Mission Profiles, Fatigue (Mechanics), Literature Surveys

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report presents the results of a 6-month technical effort to develop a realistic mission profile for each of six helicopter types in current and future Army inventories: observation, utility, utility/tactical assault, attack, crane, and transport. The profiles included in this report are the product of operational data gathered over two decades, starting with early NACA efforts and including extensive studies conducted by the Army Air Mobility R&D Laboratory and private enterprise.

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(i)

20. (cont.)

This effort was accomplished in four tasks:

Task I was a study and analysis of available literature. This included identification of 38 applicable reports, of which 31 were obtained and useful information was extracted. Included are operational studies, manufacturer's operationally derived spectra, Government specifications, flight strain data, and evaluation of previous spectra.

Task II was the combining of information obtained in Task I to develop a mission profile for each of the six helicopter types. Each profile contains the percentage of occurrence of each condition in a standardized list of steady and maneuvering conditions. Distributions of load factor with airspeed, gross weight, and altitude are presented. The developed profiles are compared to one another, and differences are discussed relative to the mission assigned.

Task III was an evaluation of the developed mission profiles. Each profile was evaluated with respect to (1) the degree of correlation with the operational data, (2) differences from design criteria, (3) current military and Government specifications, and (4) the intended mission assignment from a practical standpoint, discussing possible bias in the operational data.

The Task IV objective was to identify critical segments and conditions. Three criteria were used: high loads, high fatigue damage, and high vibration.

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INTRODUCTION

This final report is submitted as part of the required documentation under Contract DAAJ02-74-C-0018 between the U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia (USAAMRDL), and Hughes Helicopters, Culver City, California. Technical effort under this contract began in December 1973 and concluded in May 1974. Work done under this contract is a continuation of efforts by the Army to improve and update structural design criteria for future helicopters. This effort was preceded by USAAMRDL contracts with four helicopter manufacturers: Sikorsky Aircraft Division of United Aircraft Corporation (Reference 20), Bell Helicopter Company (Reference 21), The Boeing Company, Vertol Division (Reference 22), and Hughes Helicopters (Reference 23). The manufacturer of each helicopter type derived a mission profile applicable to that type of helicopter. As a natural consequence of the independent development of fatigue mission profiles for helicopters over the last several decades, each manufacturer derived the profile from different points of view using different analytical techniques. The major task in this project was to integrate these varying approaches to obtain a consistent method for deriving the mission profile for the six helicopter types (observation, utility, utility/tactical assault, attack, crane, and transport).

TASK I - STUDY AND ANALYSIS OF AVAILABLE LITERATURE

The objective of this task was to survey both civilian and military literature to obtain a data bank as the basis for mission profile development, evaluation of developed profiles, and identification of critical segments and basic conditions. Literature has been obtained including Government specifications, operational data, and manufacturer's design and operational reports. Several flight load studies, which may contain data applicable to the various tasks of this report, were identified (References 24 through 30) but could not be obtained in time to be used in this report. A total of 38 reports were identified as part of this task. These are listed in the bibliography, and an abstract of each is given in the appendix. A summary of the subjects included in each report is given in Table I. Each report is listed across the top of the table by the number corresponding to the bibliography. A dot appears if the referenced report contains data applicable to the subjects listed in the left-hand column.

TABLE I. LITERATURE SUBJECT MATRIX

Subject	Report Reference Number																																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
OBSERVATION HELICOPTER	•							•	•	•									•				•									•				•	•	
UTILITY HELICOPTER	•			•	•	•	•	•	•									•													•		•			•	•	
UTILITY/TACTICAL ASSAULT HELICOPTER							•				•			•				•															•			•	•	•
ATTACK HELICOPTER	•															•					•											•	•			•		
CRANE HELICOPTER	•							•		•		•					•			•											•	•						
TRANSPORT HELICOPTER	•								•	•			•		•							•												•	•			
GOVERNMENT SPECIFICATION	•	•	•																													•						
DESIGN SPECIFICATION																				•	•	•	•								•							•
OPERATIONAL FLIGHT CONDITION SPECTRA				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•								•	•	•	•	•			•
MAJOR SEGMENT BREAKDOWN		•		•	•	•	•	•		•	•	•	•	•	•	•	•	•	•	•	•	•	•								•	•		•	•			
BASIC CONDITION BREAKDOWN	•	•	•																	•	•	•	•								•							
PERCENTAGE OF OCCURRENCE BREAKDOWN	•	•	•																	•	•	•	•								•							
FLIGHT TIME DISTRIBUTION FOR ALTITUDE				•				•	•		•	•	•	•	•	•	•	•	•												•	•	•	•	•			
FLIGHT TIME DISTRIBUTION FOR GROSS WEIGHT											•	•	•	•	•	•	•	•	•												•	•		•	•			
FLIGHT TIME DISTRIBUTION FOR ROTOR SPEED							•			•	•	•	•	•	•	•	•	•	•													•	•	•	•			
FLIGHT TIME DISTRIBUTION FOR AIRSPEED				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•												•	•	•	•	•		•	
FLIGHT TIME DISTRIBUTION FOR LOAD FACTOR				•	•	•	•	•	•	•	•	•	•	•	•	•	•	•	•												•	•	•	•	•		•	
FLIGHT STRAIN DATA									•											•	•	•	•														•	
STRESS ANALYSIS – FATIGUE RATE DATA																				•	•	•	•															
CRITICAL CONDITION IDENTIFICATION																					•	•	•															
EVALUATION AND COMPARISON OF VARIOUS FLIGHT CONDITION SPECTRA																				•	•	•	•								•	•						

TASK II - MISSION PROFILE DEVELOPMENT

The objective of this task was to develop a standard mission profile including a list of significant flight and ground conditions with a percentage of occurrence for each condition and a distribution of airspeed, altitude, and gross weight with load factor for the six helicopter types. Mission segment time percentages were determined by using the operational data to the fullest extent possible. The operational data, in conjunction with the manufacturers' design and operational studies, were used to distribute time at the basic condition level. As pointed out in all the design and operational studies, the operational data were open to various interpretations. The design spectra and the methods of interpretation of the operational data used by each manufacturer were studied. To eliminate inconsistencies and contradictions between different manufacturers, these spectra and methods were modified as necessary based on conversations with manufacturers' representatives and this contractor's experience. Areas which required such modification or interpretation are noted, and the consequences are explained in the detailed description which follows.

MISSION SEGMENTS

The first step in developing the standard mission profile was to rigorously define meaningful mission segments among which the operational data could be divided. Six segments were defined as follows:

1. Ground Conditions. This segment includes all conditions that are conducted on the ground. All these conditions will have low engine torque values and zero rate of descent. This segment does not include takeoff and landing.

2. Takeoff, Landing, and Low-Speed Flight Conditions. This segment includes all flight conditions that are conducted below 40 knots except autorotation landings.

3. Ascent Conditions. This segment includes any condition which has a sustained rate of climb greater than 300 fpm and an airspeed greater than 40 knots. All maneuvers initiated from these conditions are also part of this segment.

4. Forward Flight Conditions. This segment consists of all flight conditions and maneuvers initiated from those conditions which

are conducted at airspeeds greater than 40 knots and have neither a sustained rate of climb nor a descent rate greater than 300 fpm.

5. Descent Conditions. This segment covers all powered flight conditions and maneuvers initiated from those conditions which have a sustained rate of descent greater than 300 fpm and an airspeed greater than 40 knots.

6. Autorotation Conditions. Included in this segment are all power-off flight conditions and maneuvers initiated from a power-off condition (includes power recovery). A flight condition enters the regime of this segment at the instant of power loss.

These segments were chosen primarily on the basis that each has a notably different fatigue damage rate due to the amount of power required or the unusual airflow associated with transition between hover and forward flight. The definitions are intended to eliminate any ambiguity in the process of editing operational data and to facilitate use of data already collected. One of the main distinctions of these mission segments, compared to those used previously, is that these do not include a separate maneuver segment. This is done in recognition of the fact that maneuvers occur in all phases of flight. The broad distribution of the maneuver segment in the operational data over rate of climb (e.g., Reference 19, page 28, Figure 9b) shows that maneuvers occur in all segments. Operational data were separated into these six segments using the torque, airspeed, and rate-of-climb histograms, where available. A priority of parameters was established according to the definitions above. That is, the time in a given segment of operational data was divided among the six standard segments by first deducting the amount in autorotation (defined here as less than 10 percent torque), followed by deducting the portion below 40 knots, and then the remainder of the operational segment was divided equally among ascent, descent, and forward flight. This was done for all references which presented data in this form. The operational data which did not have all the necessary histograms or were in a three-segment presentation required modification of this technique and assumptions that missing data followed trends similar to the other data on the same type of helicopter. The operational reports did not cover ground conditions. A value of 4 percent was assigned for ground conditions based on the number of takeoffs and landings given for some of the helicopter types in the operational data. The results of this step are shown in Figure 1 for each helicopter type. These six segments will be referred to as "the standard segments" throughout this report.

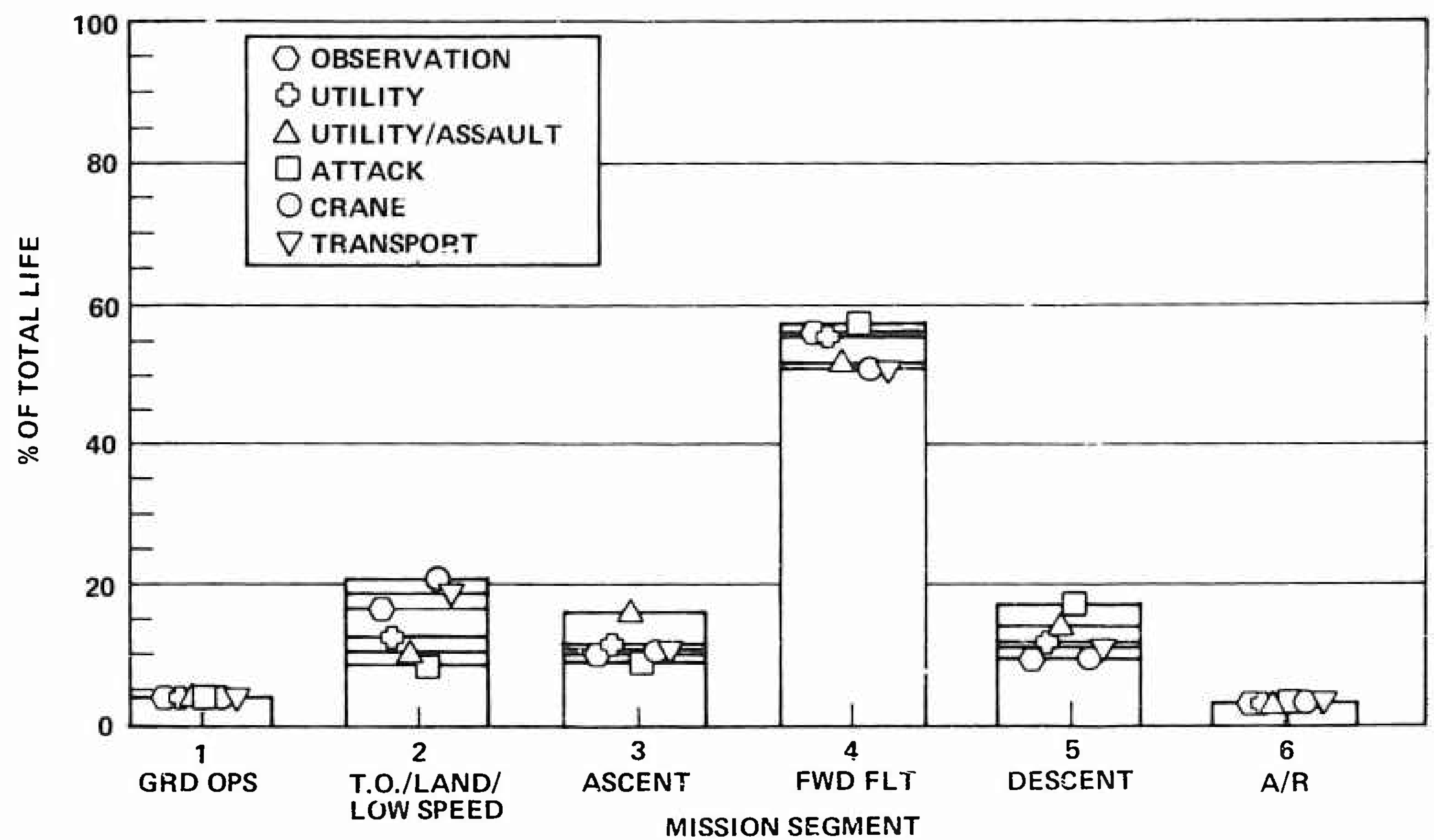


Figure 1. Mission Segment Comparison.

BASIC CONDITIONS

The second step in developing a standard profile was to create a list of basic conditions. All the design and operational reports (References 20 through 23), as well as AR-56 (Reference 1), CAM-6 (Reference 2), and AMCP 706-203 (Reference 3), were used to compile this list. Further, the lists of proposed standard mission segments and basic conditions occurring in each segment were taken to Boeing-Vertol, Sikorsky, Kaman Corporation, Technology Inc., and Bell to discuss their completeness and applicability for use in developing a fatigue survey spectrum. All of these companies had favorable comments on the standard mission segments. Suggestions were made to add some basic conditions and to delete others from some segments. Generally, deleted conditions were those which did not apply to certain segments. For example, control reversals were deleted from the ascent, descent, and autorotation segments. The resulting basic condition list is shown in the left-hand column of Table II. Each basic condition may encompass several detailed flight conditions. For example, the turn condition which appears in segments 2 through 6 may encompass right, left, S, and steep turns with varying rates of entry and recovery. (To achieve a profile in such detail is beyond the scope of this program.)

SUBDIVISION OF SEGMENTS

Segments 2 through 5 were divided into a time portion covering steady conditions and a time portion for maneuvering conditions. The time for the six standard segments was accumulated from contributions from each of the four operational segments based on rate of climb, power, and airspeed. According to the segment definitions of the operational data, the maneuver portion of any standard segment could have come from the maneuver, ascent, or descent operational segments. This overlap makes the operational data impossible to interpret precisely. Each manufacturer preparing References 20 through 23 handled this problem somewhat differently, each recognizing that a judgment was required. No consistent interpretation of the operational data could be achieved for this purpose. It was clear that much of the maneuvering during takeoff and landing (Segment 2) was included in the ascent or descent operational segment, although in widely varying amounts from one type of helicopter to another. The maneuver portion of Segment 2 was determined using varying amounts of time from the operational ascent and descent segments depending on times given in the manufacturer's design spectrum and judgment based on comparing the six missions. The utility and the utility/tactical assault helicopters had very limited operational data in a form usable for determining the maneuver portion of the segments. The other segments showed a reasonable relationship to each other and to the design spectrum using just the time from the operational maneuver segment.

The data that were available for the utility/tactical assault helicopter (References 11 and 14) were contradictory. Reference 14 showed 54 percent for the maneuver segment, while Reference 11 showed 12.19 percent. A value of 40 percent was felt to be a representative amount for this type of helicopter, as the 12.19 percent in Reference 11 does not appear to be realistic. There were no rate-of-climb histograms available for other than the steady segment, in these reports. Reference 18 was used as the most representative for rate-of-climb data. This resulted in segment percentages comparing very well with other helicopter types for standard Segments 3 through 5. However, the takeoff, landing, and low-speed segments had a considerably lower percentage of occurrence than all other types. This is a result, as discussed above, of takeoffs and landings being included in the operational ascent and descent segments. There were no design and operational reports available for the utility/tactical assault type or the utility type discussed below. Because of this lack of data, a value between the attack and observation types of 65 percent was estimated for the maneuver portion of standard Segment 2. This is based on the number of takeoffs and landings that this type of vehicle would be expected to make in hostile areas.

The data available for the utility helicopter was also very limited. Although there are a comparatively large number of reports dealing with the utility helicopter, all of those available were done prior to 1966. The data from Reference 18 were used to calculate the portion of each standard segment spent maneuvering. This resulted in values below all other helicopter types for Segments 2 through 5. Clearly, this is out of line with the utility mission. This is a result of the value of only 1 percent given to the maneuver segment in Reference 18. Values were assigned for the maneuver percentages for the standard segments below the values for the attack and utility/tactical assault helicopters, and above the crane and transport values. The takeoff and landing segment was given a value greater than that for the attack helicopter, reflecting the increased activity during takeoff and landing and the similarity to the observation and utility/tactical assault types for the segment. The values resulting from this discussion are shown in Figure 2. Segment 6 is discussed separately later in this task.

TABLE II. STANDARD MISSION FROFILE

Condition	Helicopter Type (percentage of occurrences)					
	Obser-vation	Utility	Utility/ Assault	Attack	Crane	Trans-port
1. GROUND OPERATIONS						
A. Startup	0.50	0.50	0.50	0.50	0.50	0.50
B. Shutdown	0.50	0.50	0.50	0.50	0.50	0.50
C. Ground run	2.00	2.00	2.00	2.00	2.00	2.00
D. Taxi (if aircraft has no wheels, transfer to 2.K)	1.00	1.00	1.00	1.00	1.00	1.00
	4.00	4.00	4.00	4.00	4.00	4.00
2. TAKEOFF/LANDING/LOW-SPEED FLIGHT (<40 knots)						
A. Vertical lift-off (includes transition to 40 knots)	2.66	1.58	0.43	0.22	0.51	0.66
B. Rolling takeoff (if aircraft has no wheels, add to 2.A)	0	0	0.43	0.27	1.24	1.53
C. Vertical landing	2.66	1.58	0.43	0.22	0.51	0.66
D. Slide-on landing (if aircraft has no wheels, add 90 percent to 2.C)	0	0	0.43	0.27	1.24	1.53
E. Hover (steady)	0.33	2.81	1.61	0.69	6.18	4.14

TABLE II - Continued

Condition	Helicopter Type (percentage of occurrences) Obser-vation	Utility	Utility/ Assault	Attack	Crane	Trans-port
F. Hover control reversals	0.45	0.31	0.78	0.25	0.97	0.43
G. Hover turns	0.45	0.31	1.04	0.25	1.49	1.22
H. Pop-ups	0.71	0	0.34	0.48	0.53	0
I. Sideward flight	0.45	0.31	0.70	0.25	0.87	0.43
J. Rearward flight	0.23	0.16	0.39	0.13	0.61	0.23
K. Low-speed forward flight (air taxi)	1.29	2.78	1.50	2.77	1.12	4.13
L. Flare	2.67	1.50	0.78	0.48	0.53	2.45
M. Vertical climb	0.33	0.42	0.22	0.69	2.24	0.29
N. Vertical descent	0.33	0.42	0.22	0.69	2.24	0.29
O. Low-speed turns	4.09	0.74	0.87	0.87	0.61	1.22
	16.65	12.92	10.17	8.53	20.89	19.21
3. ASCENT (>40 knots)						
A. Steady-state climb	8.36	9.00	10.35	3.66	9.91	9.83
B. Turns	1.45	2.32	4.65	4.34	0.65	0.99
C. Pushovers	0.34	0.34	1.23	1.16	0	0
	10.18	11.66	16.23	9.16	10.56	10.82

TABLE II - Continued

Condition	Observation	Utility	Utility/ Assault	Attack	Crane	Transport
	Helicopter Type (percentage of occurrences)					
4. FORWARD FLIGHT (>40 knots)						
A. Level flight	38.08	39.02	30.13	33.40	47.58	46.28
B. Turns	8.14	9.91	10.26	11.65	3.02	3.43
C. Control reversals	1.50	1.27	1.13	0.63	0.10	1.51
D. Pull-ups	2.04	0.25	2.54	2.85	0.05	0.10
E. Pushovers	2.04	0.03	2.54	2.85	0	0.01
F. Deceleration	2.04	2.55	2.54	2.85	0.30	0
G. Acceleration	2.04	2.55	2.54	2.85	0.30	0
H. Yawed flight	0.38	0.34	0.44	0.51	0.08	0.10
	56.26	55.92	52.12	57.59	51.43	51.43
5. DESCENT (power on, >40 knots)						
A. Partial power descent (steady descent)	2.07	5.26	3.18	2.21	9.10	7.97
B. Dive (power on)	3.37	3.50	5.09	3.45	0.05	2.12
C. Turns	3.30	3.31	4.65	9.27	0.61	1.09
D. Pull-ups	0.84	0.10	1.23	2.46	0.03	0.03
	9.58	12.17	14.15	17.39	9.79	11.21

TABLE II - Continued

Condition	Helicopter Type (percentage of occurrences)					
	Observation	Utility	Utility/ Assault	Attack	Crane	Transport
6. AUTOROTATION (power off)						
A. Entries (includes power chops)	0.39	0.39	0.39	0.39	0.39	0.39
B. Steady descent	1.63	1.63	1.63	1.63	1.63	1.63
C. Turns	0.55	0.55	0.55	0.55	0.55	0.55
D. Power recovery	0.24	0.24	0.24	0.24	0.24	0.24
E. Flare and landing	0.52	0.52	0.52	0.52	0.52	0.52
	3.33	3.33	3.33	3.33	3.33	3.33

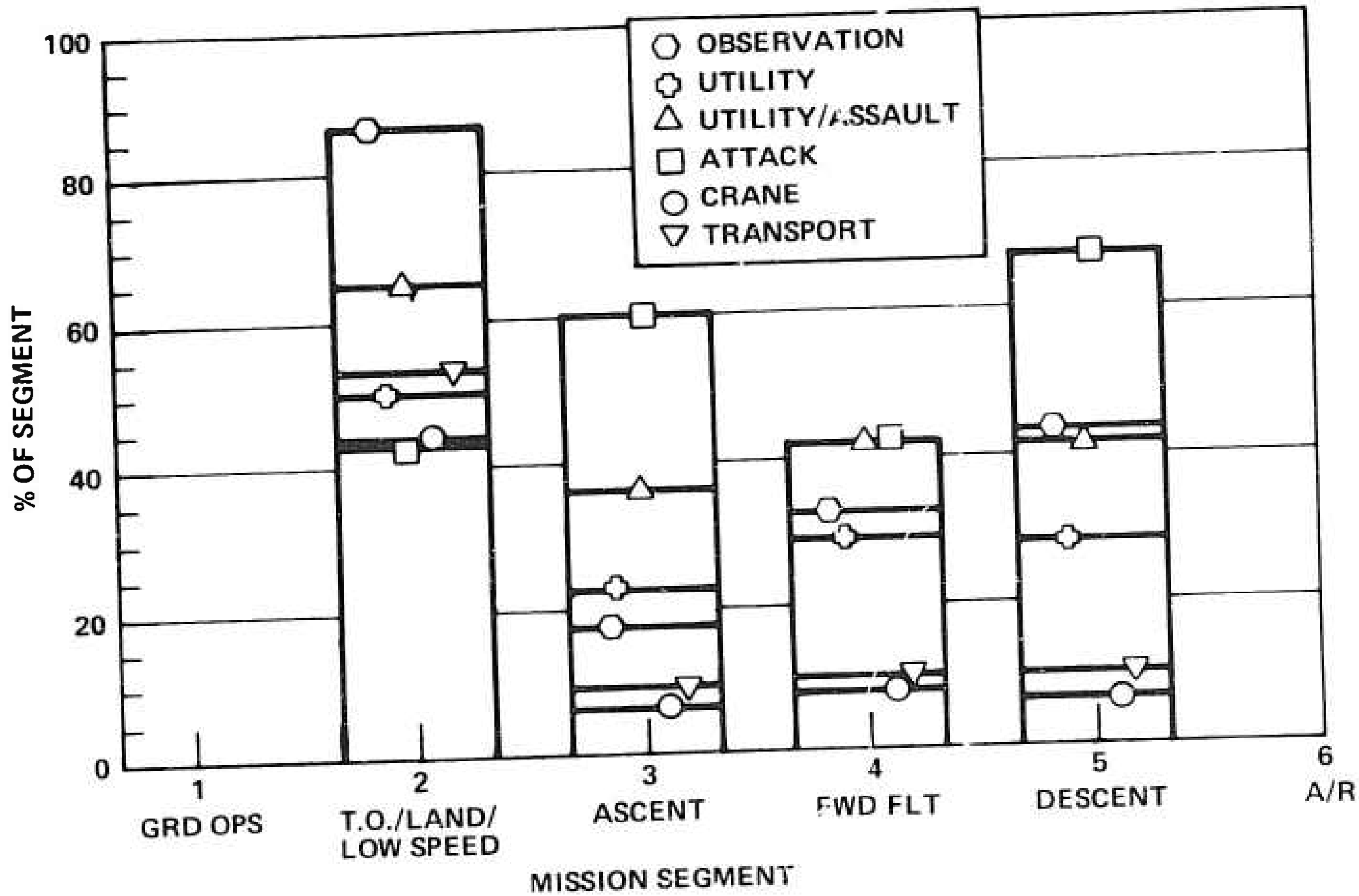


Figure 2. Maneuver Portion of Segments for Derived Spectra.

SEPARATION OF LOAD-FACTOR-PRODUCING CONDITIONS

An attempt was made to further break down the maneuver portions obtained above into load-factor-producing maneuvers and maneuvers not producing load factor. Most of the operational reports contain load factor peak tables and exceedance curves. In order to use these data to accomplish this breakdown, a number of assumptions were made. Since the tables do not deal with individual segments, a distribution of peaks among the segments was assumed. The data are given in terms of load factor peaks; therefore, a maneuver duration time was assumed to convert to time units. Values of maneuver durations for the various basic conditions are presented in Table III. Assumptions of this type were made using the most conservative durations for the attack data (Reference 16). The times obtained for load-factor-producing conditions were far less than the design spectrum. This approach was dropped as a method of determining the load-factor-producing portion of the segments. The load factor peak curves and tables were, however, used to determine the distribution of load factor with gross weight, altitude, and airspeed. This is discussed later in this task.

BASIC CONDITION PERCENTAGE OF OCCURRENCE

Instead of the above, a more conservative and straightforward approach was adopted using the design spectrum proportions to obtain a first cut at basic condition percentages for the maneuver and steady categories of each segment. Some basic conditions were not included by some manufacturers; percentages were estimated for these based on comparison with other spectra, AR-56, and experience. Basic condition percentages were obtained for each helicopter type for which there was a design spectrum available. Design spectra were not available for the utility or utility/tactical assault helicopters. In order to provide a guide for these two, as well as to arbitrate the tendency of different manufacturers to accent one condition more than others, the percentage of occurrence figures were tabulated for each of the six types for each basic condition. This pointed out a large number of differences in the takeoff and landing segment and the autorotation segment with only a few differences in the other segments.

Segment 2 was treated by normalizing the basic condition percentage of occurrences to account for differences in segment time. These were plotted on a single graph to obtain a visual conception of the relative magnitudes for the different helicopter types. These were then modified based on a comparison of the mission assigned to each type helicopter.

TABLE III. MANEUVER DURATIONS

Condition	Duration (sec)					
	Obser-vation	Utility	Utility/ Assault	Attack	Crane	Trans-port
1. GROUND OPERATIONS						
A. Startup						
B. Shutdown						
C. Ground run						
D. Taxi						
2. TAKEOFF/LANDING/LOW-SPEED FLIGHT (<40 knots)						
A. Vertical lift-off and acceleration	10	10	10	8	12	12
B. Rolling takeoff	10	10	10	8	12	12
C. Vertical landing	3	3	3	3	3	3
D. Slide-on landing	10	10	10	8	12	12
E. Hover (steady)						
F. Hover control reversals	3	3	3	3	3	3
G. Hover turns	6	6	8	8	10	10
H. Pop-ups	3	3	3	3	3	3
I. Sideward flight						
J. Rearward flight						

TABLE III - Continued

Condition	Duration (sec)					
	Obser-vation	Utility	Utility/ Assault	Attack	Crane	Trans-port
K. Low-speed forward flight (air taxi)						
L. Flare	15	15	15	15	15	15
M. Vertical climb						
N. Vertical descent						
O. Low-speed turns	6	8	6	6	10	10
3. ASCENT (>40 knots)						
A. Steady-state climb						
B. Turns	6	8	6	6	10	10
C. Pushovers	3	3	3	3	3	3
4. FORWARD FLIGHT (>40 knots)						
A. Level flight						
B. Turns	6	8	6	6	10	10
C. Control reversals	3	3	3	3	3	3
D. Pull-ups	3	3	3	7	3	3
E. Pushovers	3	3	3	3	3	3
F. Deceleration	15	15	15	15	15	15

TABLE III - Continued

Condition	Duration (sec)					
	Obser-vation	Utility	Utility/ Assault	Attack	Crane	Trans-port
G. Acceleration	15	15	15	15	15	15
H. Yawed flight						
5. DESCENT (power on, <40 knots)						
A. Partial-power descent (steady descent)						
B. Dive (power on)						
C. Turns	6	8	6	6	10	10
D. Pull-ups	3	3	3	3	3	3
6. AUTOROTATION (power off)						
A. Entries (includes power chops)	3	3	3	2	3	3
B. Steady descent						
C. Turns	6	8	6	6	10	10
D. Power recovery	3	3	3	3	3	3
E. Flare and landing	10	10	10	10	10	10

Segment 6 is primarily a training exercise and not directly related to the mission assigned. This supports the conclusion that the basic conditions should have the same proportion of the segment regardless of helicopter type. A single or dual powerplant is the predominant factor governing the time for the entire segment. Multiengine aircraft will rarely do full autorotations, even in practice. It is concluded that the autorotation segment percentages should be the same for all types; however, for multiengine aircraft, these conditions are performed with one engine on. The autorotation segment time was taken as the average of the time at less than 10 percent torque for all types. The distribution of this time among the basic conditions was determined using an average of all the design spectra, AMCP 706-203, AR-56, and CAM-6.

The distribution among the basic conditions of Segment 1 was handled in a similar manner. The percentages of occurrences obtained from this approach are presented in Table II.

DISTRIBUTION OF LOAD FACTOR WITH AIRSPEED, GROSS WEIGHT, AND ALTITUDE

Load factor distributions with airspeed, gross weight, and altitude are presented in Figures 3 through 20. These data represent composites of data currently available from published reports of flight loads surveys during test and operational usage of various types of helicopters. The distributions are indicative of either a combat environment or a peacetime environment, and in some instances, a composite of both environments. The available reports were grouped according to the six types of helicopters. From each group of reports, a composite percentage of load factor peaks was compiled for each type. The load factor values were normalized to a load factor ratio in terms of delta peak load factor/delta limit load factor ($\Delta N_Z/\Delta N_L$). Delta limit load factor was defined as the design limit value minus 1g (N_L -1) at maximum design gross weight. For example, a peak load factor of 1.60g at a design limit value of 2.0g would correspond to a load factor ratio of +0.6 ($\Delta N_Z/\Delta N_L = (1.6-1)/(2-1)$). For those load factor ratio ranges where no percentage values are indicated, either no peaks occurred or no data were available. The available flight loads reports lacked data near the 1.0g level. Occurrence of load factor peaks approaches infinity for load factors near the 1g level. This is signified by the vertical dashed lines on the load factor-airspeed distribution curves. For data editing purposes during these studies, threshold values of 0.85g and 1.15g were established and all peaks occurring between these values were ignored.

The load factor-airspeed distributions for each type were separated into a different distribution for each range of airspeed, where airspeed is presented in terms of percent V_H. An attempt was made to present airspeed ranges which corresponded as closely as possible to the increments presented in the standard mission segments; however, the increments shown were dictated somewhat by the increments presented in the reports used to compile these distributions.

The load factor-gross weight distributions are presented in terms of percentage of load factor peaks in ranges of gross weight ratios. Gross weight ratio was defined as gross weight divided by maximum design gross weight. Values of maximum design gross weight were obtained from the vehicle characteristics for each helicopter type as presented in the available literature. The ratios were broken into segments corresponding to a low, mid, and high gross weight for each type of vehicle. Again, the increments presented were dictated by the available data used to compile the distributions and the maximum design gross weights of the types of helicopter surveyed.

The load factor-altitude distributions are similar in format to the gross weight distributions except that they are plotted against altitude ranges expressed in feet.

To establish the gross weight and altitude distributions with load factor, a percentage was determined for each load factor increment based on the distribution shown in the "total" column of the "load factor-tip speed ratio" tables in the operational data (e.g., Reference 19, Figure 14, page 36). This percentage for each load factor level was distributed in the same ratio as the percentage of total time in each gross weight and altitude range. As an example, for the observation helicopter, the average percentage of load factor peaks in the $\Delta N_Z/\Delta N_L$ range of 0.13 to 0.19 was 43.0 percent over the total airspeed range. The gross weight distribution for the observation helicopter indicated that 66.6 percent of the time was spent in a mid gross weight range corresponding to a GW/MDGW ratio of 0.74 to 0.89. Therefore, the percentage of load factor peaks in the $\Delta N_Z/\Delta N_L$ range of 0.13 to 0.19 for gross weight ratios between 0.74 and 0.89 was determined to be $0.666 \times 43.0 = 28.6$ percent. This approach produces a gross weight and altitude distribution with load factor that is independent of airspeed. In most cases, the percentage of load factor peaks in a given $\Delta N_Z/\Delta N_L$ range did not vary significantly with airspeed for a given helicopter type.

Distributions of load factor with center of gravity were not determined because of the lack of available data. Previously published reports have not approached the subject of load factor distributions as a function of center of gravity. During most manufacturers' flight loads surveys, tests are conducted at whatever center of gravity position is determined to be the most critical for the condition being tested.

PROFILE COMPARISON BY TYPE OF MISSION

The standard mission profiles presented in this report cover six types of helicopter missions. For the most part, each mission type is distinct, although there is some overlap in capabilities and assignments. These missions are reflected in the profile for each helicopter type, and the differences may be seen by comparing the segment percentages, the portion of the segments in maneuvering, and the basic condition percentages of occurrence.

Figure 1 shows the mission segment percentages for each helicopter type. At this level, there is not much difference between the types. The greatest variation occurs in the takeoff, landing, and low-speed segment. The crane and transport helicopters are highest in this segment. This indicates a predominance of short flights or prolonged activity at takeoff and landing zones. The attack and utility/tactical assault types were lowest in the takeoff and landing segments. This indicates that these types are primarily employed for patrol and offensive missions and do not spend much time at takeoff and landing zones. The high percentage for the attack mission in the descent segment is indicative of the increased amount of diving done by an attack helicopter.

Figure 2 shows the segment time percentage spent in maneuvering conditions for each helicopter type. This figure shows major differences between the types. These differences are particularly significant because maneuvers have a strong effect on fatigue life. Each helicopter mission is described by the shape of the curve. For example, the crane and transport helicopters spend a good part of their time in Segment 2 maneuvering, with little maneuvering at speeds above 40 knots. This indicates that their maneuvering is associated with takeoff, landing, and low-speed operations probably connected with load/passenger pickup and release. Time above 40 knots is mostly straight and level flight to destination. In contrast is the attack mission curve, indicating maneuvering only as necessary for takeoff and landing at low speed with concentrated maneuvering above 40 knots, especially in ascent and descent. This is indicative of gunnery and evasive maneuvers. The other helicopter types have intermediate values for maneuvers reflecting the severity of their missions in each segment. The observation mission curve shows a high concentration of maneuvering in the low-speed segment. This may be a result of the requirement for commanders to observe activity at several hot spots in the same vicinity and possibly to dodge fire while loitering over one location.

The preceding paragraph discusses the amount of maneuvering done in each segment. The types of maneuvers performed are also very important.

The distribution of time among maneuvering conditions and steady conditions within the segment is shown by the percentages of occurrence in Table II. Looking at Segment 2, it may be seen that the observation helicopter performs a large number of turns in low-speed flight and a high percentage in the flare condition. These maneuvers would be performed to observe ground activity from various vantage points. On the other hand, the crane spends over 6 percent of its life in a steady hover. This would occur while loads are being picked up or released. The attack helicopter has the highest percentage for pop-ups, which would be performed when the helicopter pops up vertically from behind cover to fire and returns to cover. Some conditions occur so rarely that they have been given zero percentage of occurrence for some helicopter types; i.e., ascending pushovers for both the crane and transport.

It is clear from the discussion in the preceding paragraphs that the basic condition percentages of occurrence are closely related to the mission. Missions not covered or expanded missions, which may be flown by future helicopters, will require modification to the basic condition percentages of occurrence. Modification to the airspeed, gross weight, and altitude distributions with load factor may also be necessary. However, this is not recommended without additional data because distributions are given in terms of design capability (V_H, N_L, BSDWG, etc) and only determine distribution of basic condition time, not magnitude. The value for each basic condition percentage of occurrence may be estimated by comparing the new mission to the six shown. These estimates would then need to be normalized so that each segment totals to the same value as the helicopter profile most closely related to the new mission.

LOAD FACTOR DISTRIBUTION COMPARISON BY MISSION TYPE

Observation

The load factor-airspeed distribution for the observation helicopter indicates that the highest and lowest load factor levels ($\Delta N_Z/\Delta N_L$) are attained in the mid airspeed ranges (46 to 61 percent V_H). As the extremes of the airspeed spectrum are approached, the load factor envelope, indicated by the width of the histogram, decreases and the percentage values for a given $\Delta N_Z/\Delta N_L$ level decrease. However, the percentage values for maximum load factor peaks are apparently greater at the higher airspeeds than at the lower airspeeds.

The load factor-gross weight distribution indicates that the greatest percentage of load factor peaks occur in the mid gross weight range, and more peaks occur at the higher gross weight than at the lower gross weight.

The greatest percentage of load factor peaks occur in the mid altitude range of 2000 to 4000 feet.

Utility

For the utility helicopter, the distribution of load factor peaks with airspeed did not vary significantly throughout the airspeed spectrum. The only apparent difference occurs in the 60 to 80 percent V_H airspeed range, where a greater number of minimum peaks occur than in the other airspeed ranges. Note that these minimum peaks represent a small percentage of the total in the 60 to 80 percent V_H range.

The load factor-gross weight distribution indicates that the greatest percentage of load factor peaks occurred in the mid and high gross weight ranges. For a given range of $\Delta N_Z/\Delta N_L$, the percentage of peaks in the mid gross weight range was only slightly greater than the values for the high gross weight range.

The load factor-altitude distributions indicate that the greatest number of load factor peaks occurred in the mid-altitude range (2000 to 5000 feet). The percentage values in this range were significantly greater than for any other altitude range.

Utility/Tactical Assault

The distribution of load factor peaks with airspeed for the utility/tactical assault helicopter remains relatively constant throughout the airspeed spectrum; i. e., the percentage of load factor peaks for a given $\Delta N_Z/\Delta N_L$ range between 0 and 0.6 does not vary significantly. The lowest (minimum) load factor values occur in the 55 to 74 percent V_H range. However, in terms of percentage of peaks, they represent a very small portion of the total load factor spectrum.

The load factor-gross weight distribution indicates that the greatest percentage of load factor peaks occurred in the mid and high gross weight range. The percentage values in the lower gross weight range were considerably less than the values in the upper ranges.

The distribution of load factor peaks with altitude shows a gradual increase in the percentage values for a given $\Delta N_Z/\Delta N_L$ range as the altitude increases. However, at the high-altitude range (>5000 feet), the percentage values drop off considerably.

Attack

As indicated by the load factor-airspeed distribution for the attack helicopter, the range and magnitude of the load factor peaks are significantly greater than for the other helicopter types. The greatest range of $\Delta N_Z/\Delta N_L$ values occurs in the 56 to 70 percent V_H airspeed range. However, the greatest percentage of peaks in the higher load factor ranges occurred at slightly higher speeds, the 70 to 84 percent V_H range. The 70 to 84 percent V_H airspeed segment contains the largest percentages of load factor peaks in the upper ranges of $\Delta N_Z/\Delta N_L$. The percentage values vary from approximately 27 percent of the peaks in the 0.14 to 0.21 $\Delta N_Z/\Delta N_L$ range to 4 percent of the peaks in the 0.84 to 0.98 $\Delta N_Z/\Delta N_L$ range, with the other load factor levels varying between these two values. The 84 to 98 percent V_H airspeed range has an even distribution of high load factor peaks.

The load factor-gross weight distribution indicates that a minimal percentage of load factor peaks occur in the low gross weight range (GW/MDGW <0.74). The mid gross weight range extends to a relatively high value of GW/MDGW (0.95) due to the ranges for which data were available from the operational studies. The operational studies indicated that a large amount of total flight time was spent at the higher gross weights, and therefore the percentages of load factor peaks were correspondingly higher at the upper gross weights.

The load factor-altitude distribution shows that the highest percentages of load factor peaks occurred in the 2000- to 5000-foot altitude range. The lowest percentage of peaks occurred in the range of 5000 to 10,000 feet and greater than 10,000 feet.

Crane

The single feature of the load factor-airspeed distribution that is most apparent for the crane helicopter is the narrow range of $\Delta N_Z/\Delta N_L$ in which the load factor peaks occurred. The percentages of load factor peaks in the range of -0.4 to +0.4 $\Delta N_Z/\Delta N_L$ are significantly higher than the values for the other helicopter types. For each airspeed range, over 80 percent of the total number of load factor peaks occurred between $\Delta N_Z/\Delta N_L$ values of ±0.16 and 0.24. Note that this does not include unrecorded peaks occurring between $\Delta N_Z/\Delta N_L$ values of -0.15 and +0.15.

The load factor-gross weight distribution for the crane helicopter indicates that the lowest percentages of load factor peaks occurred in the mid gross weight range. The greatest percentage of peaks occurred in the low gross weight range (GW/MDGW<0.71).

The load factor-altitude distribution shows that the highest percentages of load factor peaks occurred in the 2000- to 5000-foot altitude range. The second highest percentages occurred in the upper altitude range (5000 to 10,000 feet), although the values were considerably less than those in the 2000- to 5000-foot range.

Transport

For the transport helicopter, the distribution of load factor peaks with airspeed does not vary significantly throughout the airspeed spectrum. Also, the magnitudes of the load factor peaks, as indicated by the width of the $\Delta N_Z/\Delta N_L$ band for each airspeed range, are not excessive. They compare quite closely with the values shown for the crane helicopter. As in the case of the crane helicopter, over 80 percent of the total load factor peaks in each airspeed range occurred between $\Delta N_Z/\Delta N_L$ values of ±0.15 and 0.23. Again, this does not include the unrecorded peaks occurring between $\Delta N_Z/\Delta N_L$ values of -0.15 and +0.15.

The load factor-gross weight distribution for the transport helicopter indicates that the greatest number of load factor peaks occurs in the low gross weight range. Only a very small percentage of load factor peaks at any given $\Delta N_Z/\Delta N_L$ level occur in the GW/MDGW range greater than 0.91.

The transport helicopter incurred the greatest percentages of load factor peaks in the mid altitude range of 2000 to 5000 feet. The percentage distribution of peaks in the remaining altitude ranges remained relatively constant. The percentage of peaks occurring in the altitude range greater than 10,000 feet is negligible.

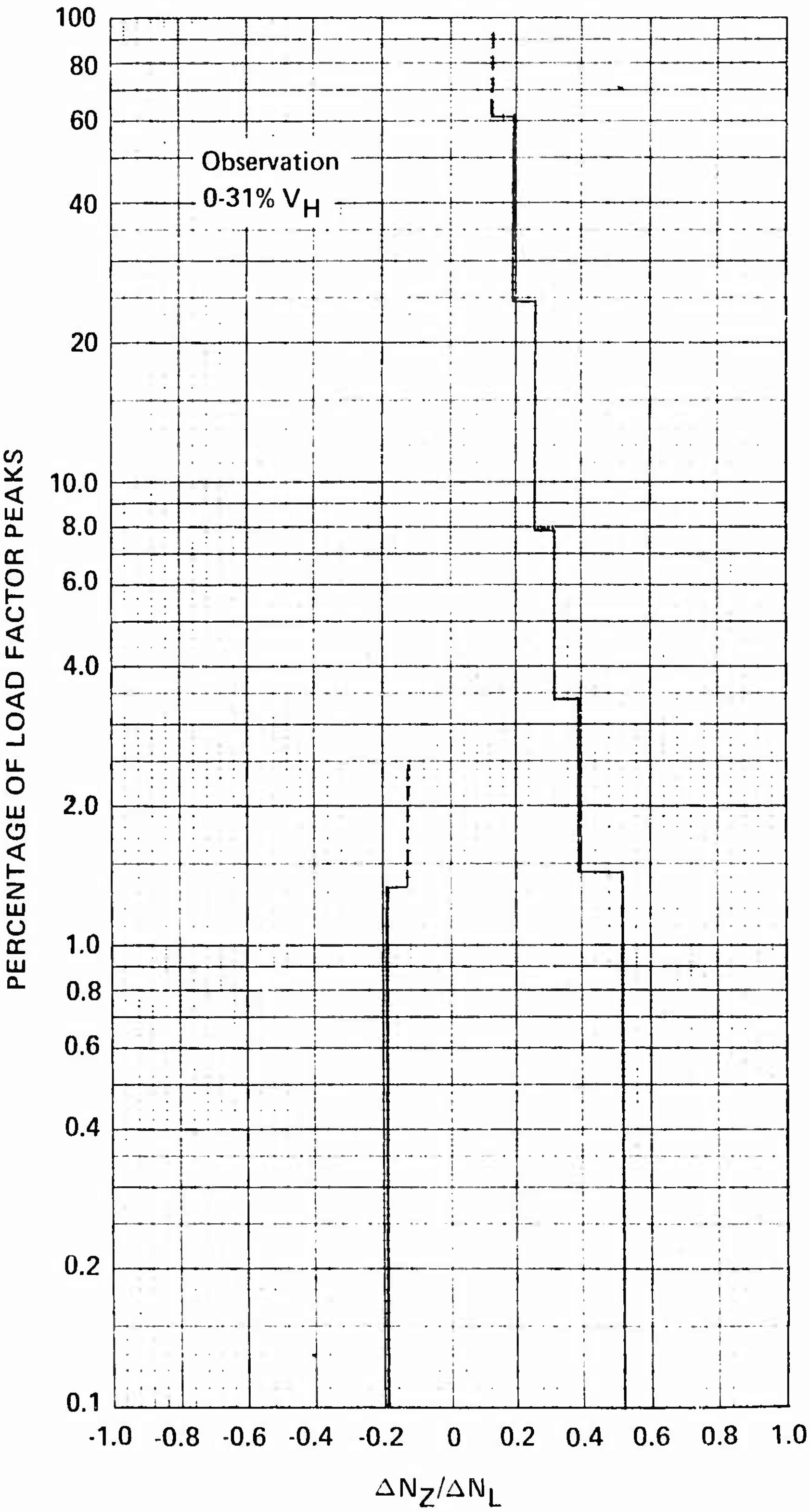


Figure 3a. Load Factor-Airspeed Distribution, Observation Type.

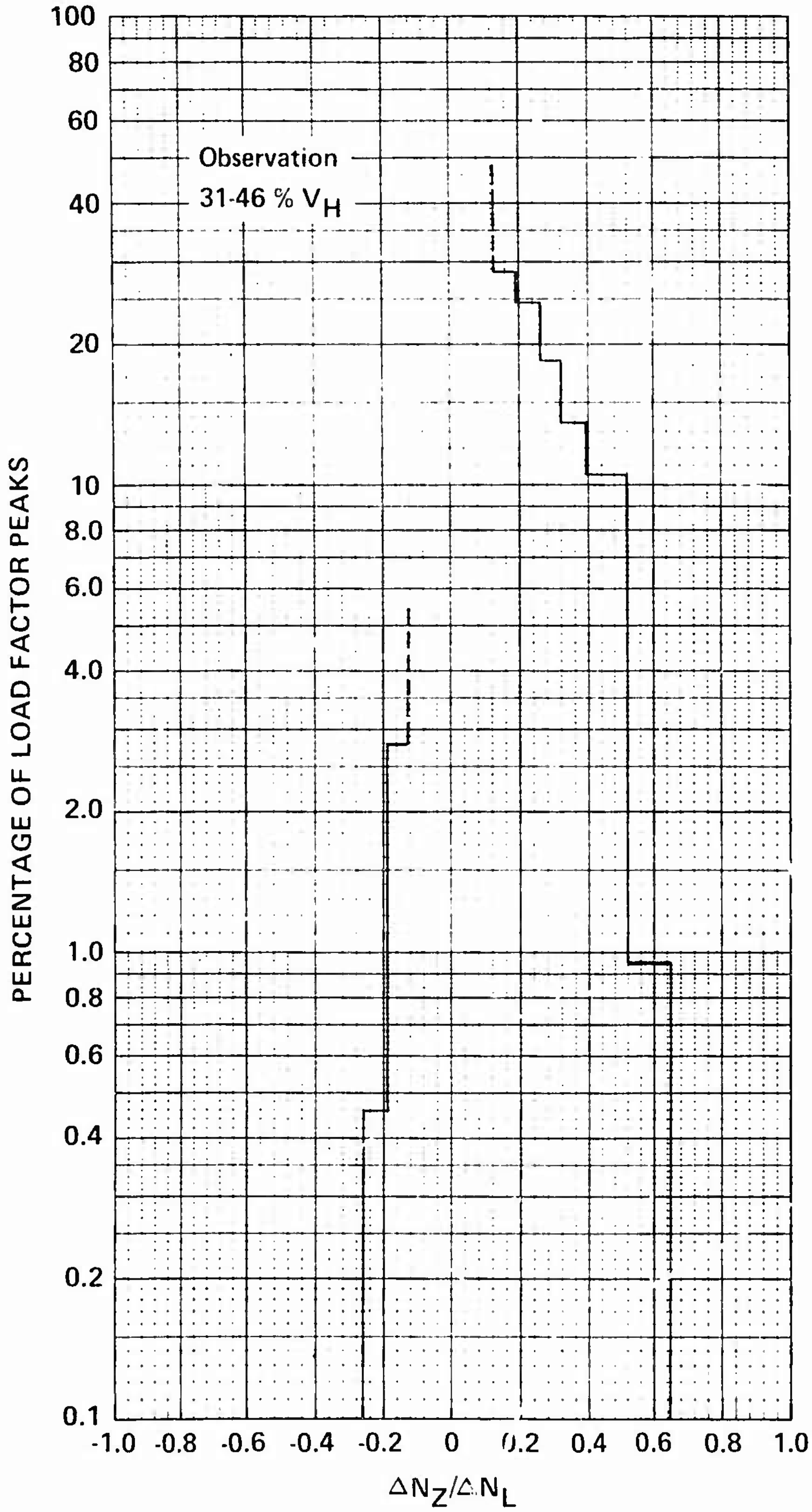


Figure 3b. Load Factor-Airspeed Distribution, Observation Type.

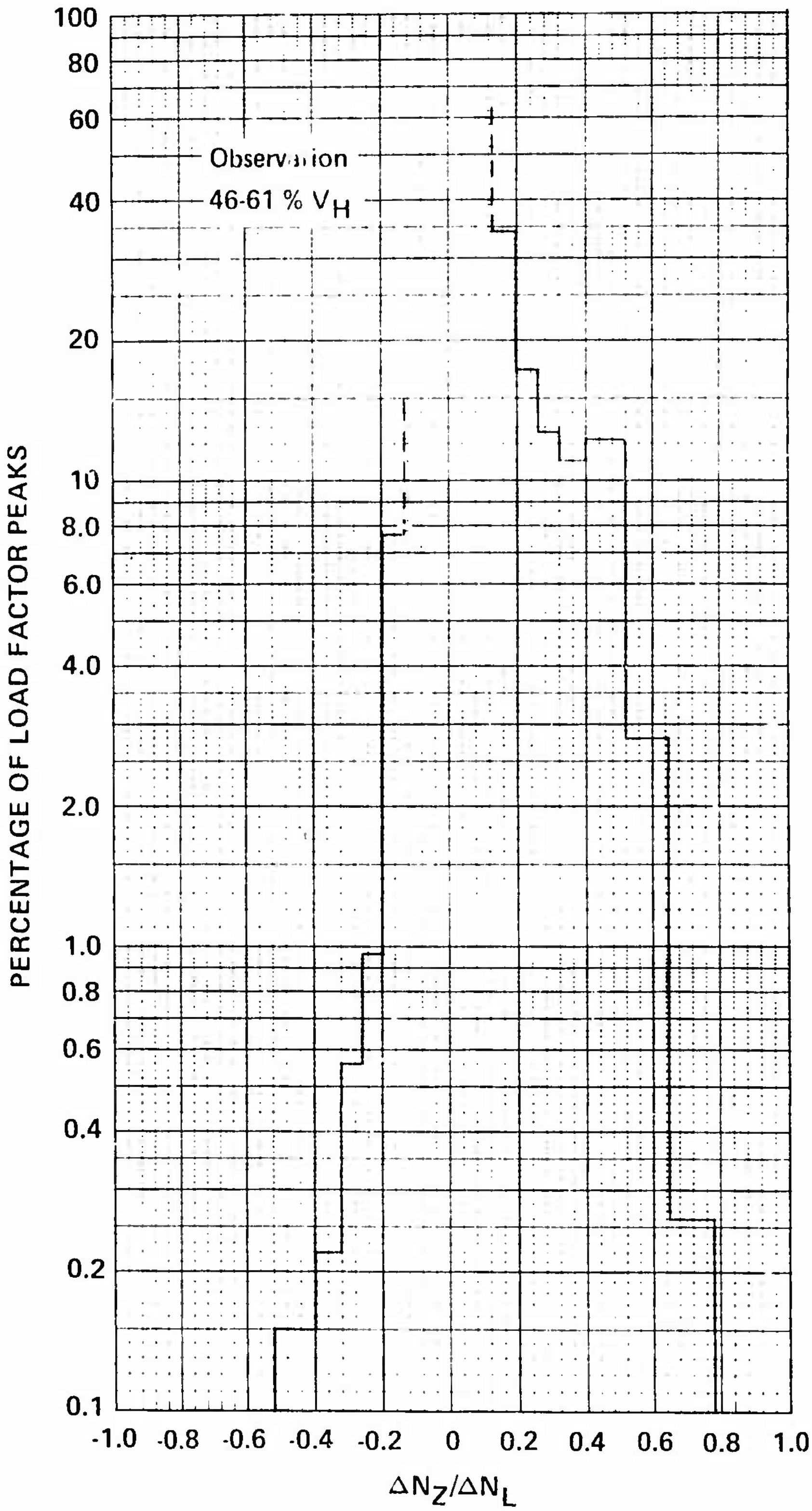


Figure 3c. Load Factor-Airspeed Distribution, Observation Type.

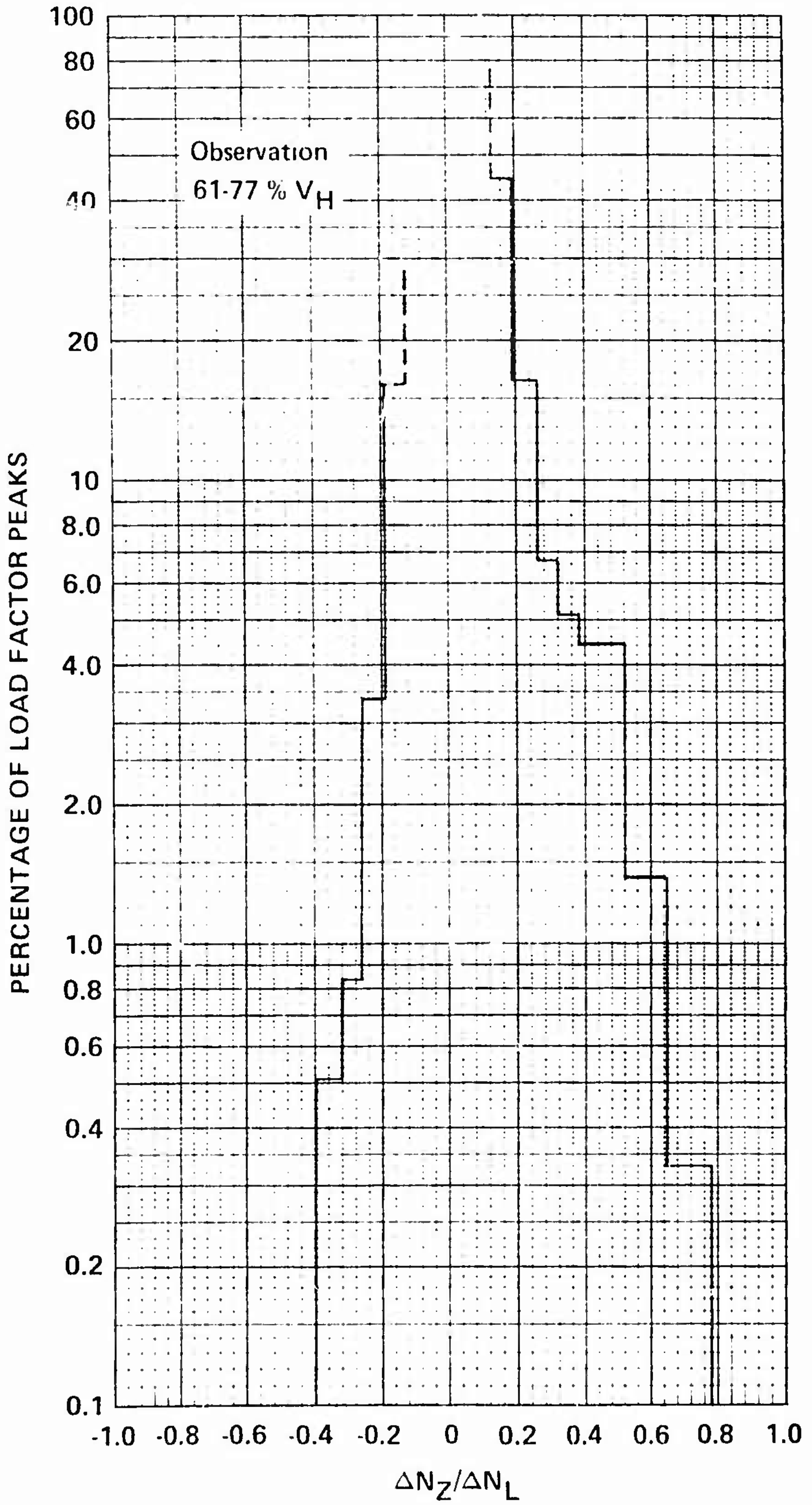


Figure 3d. Load Factor-Airspeed Distributio: Observation Type.

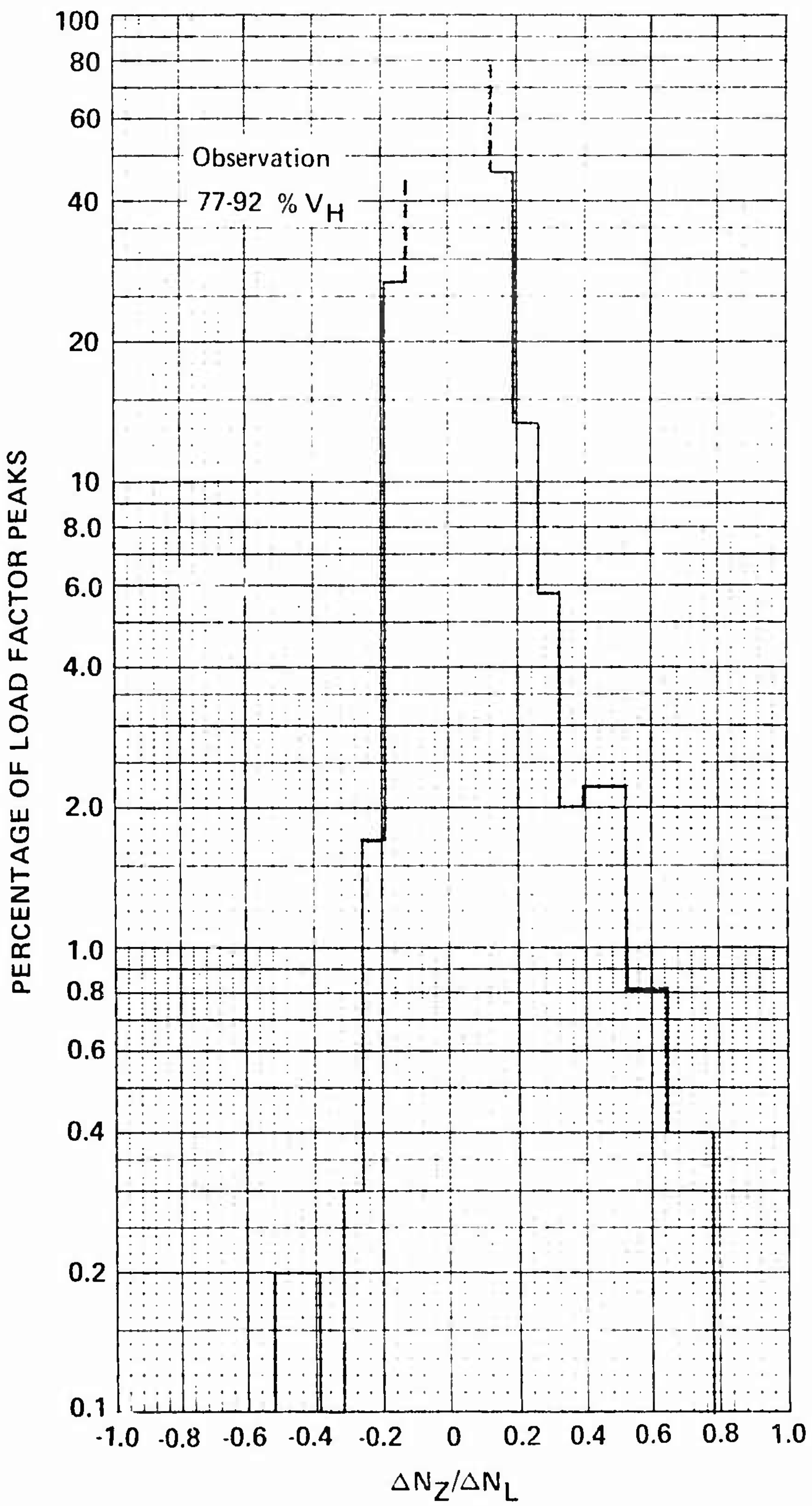


Figure 3e. Load Factor-Airspeed Distribution, Observation Type.

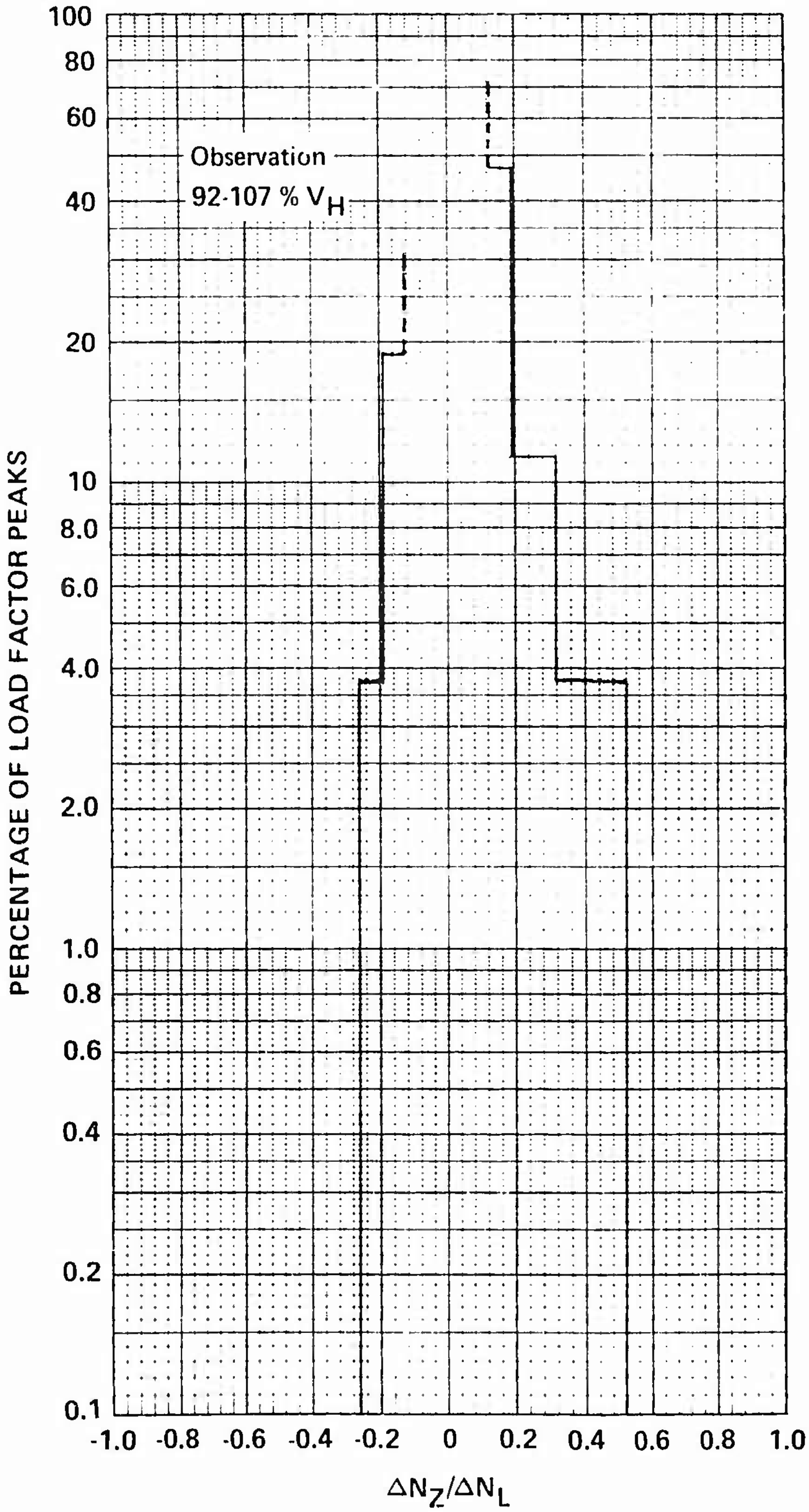


Figure 3f. Load Factor-Airspeed Distribution, Observation Type.

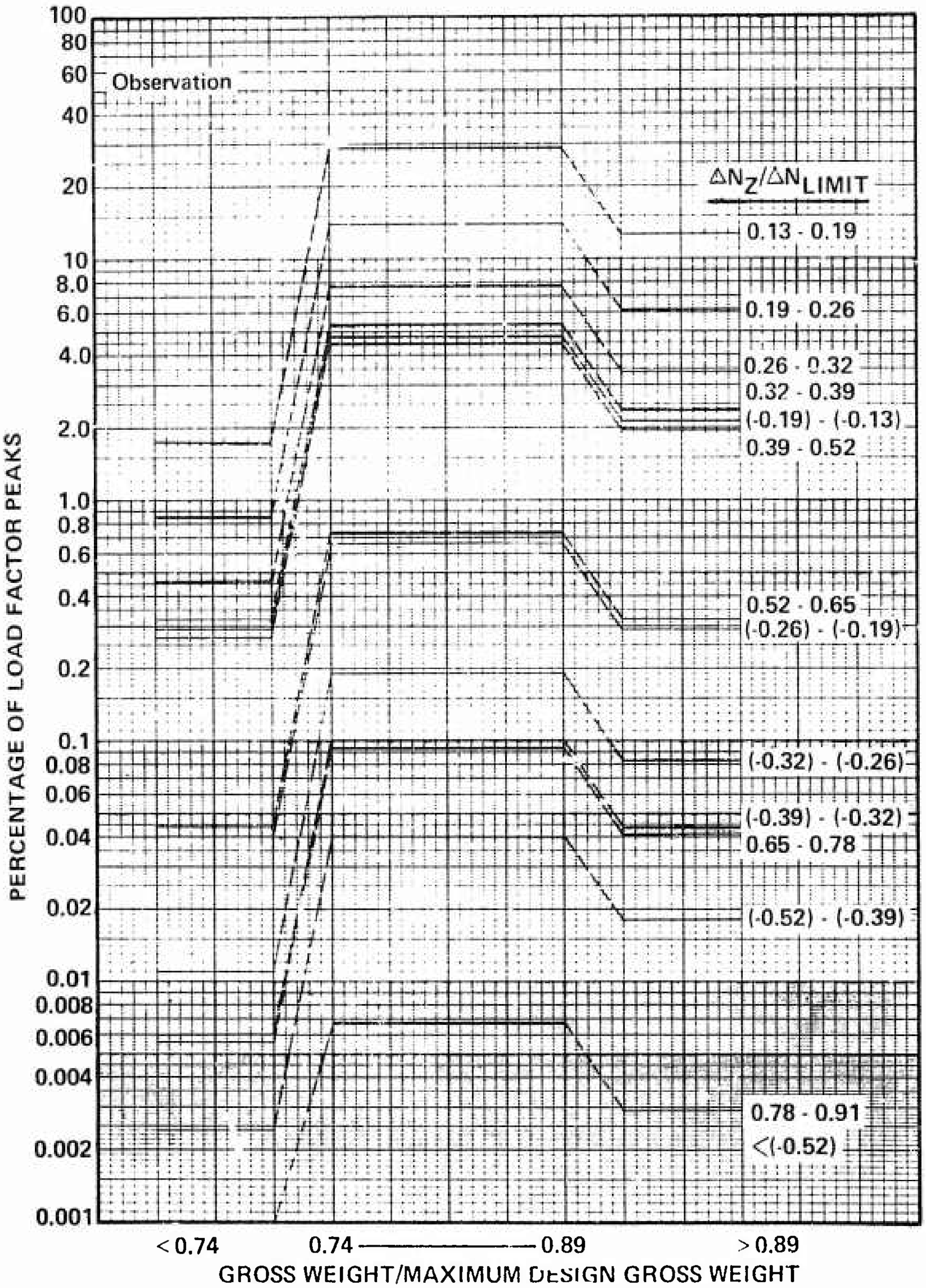


Figure 4. Load Factor-Gross Weight Distribution, Observation Type.

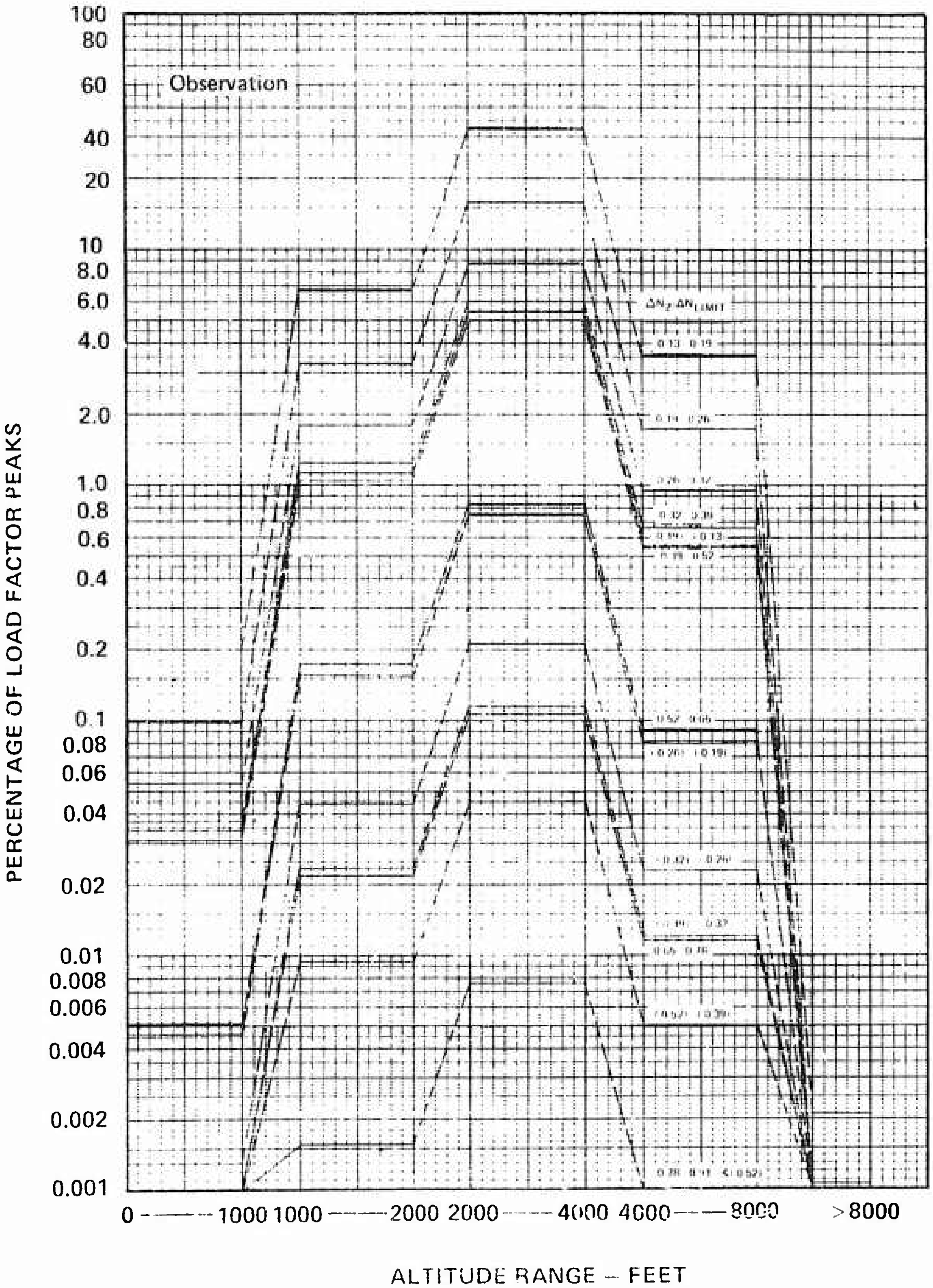


Figure 5. Load Factor-Altitude Distribution, Observation Type.

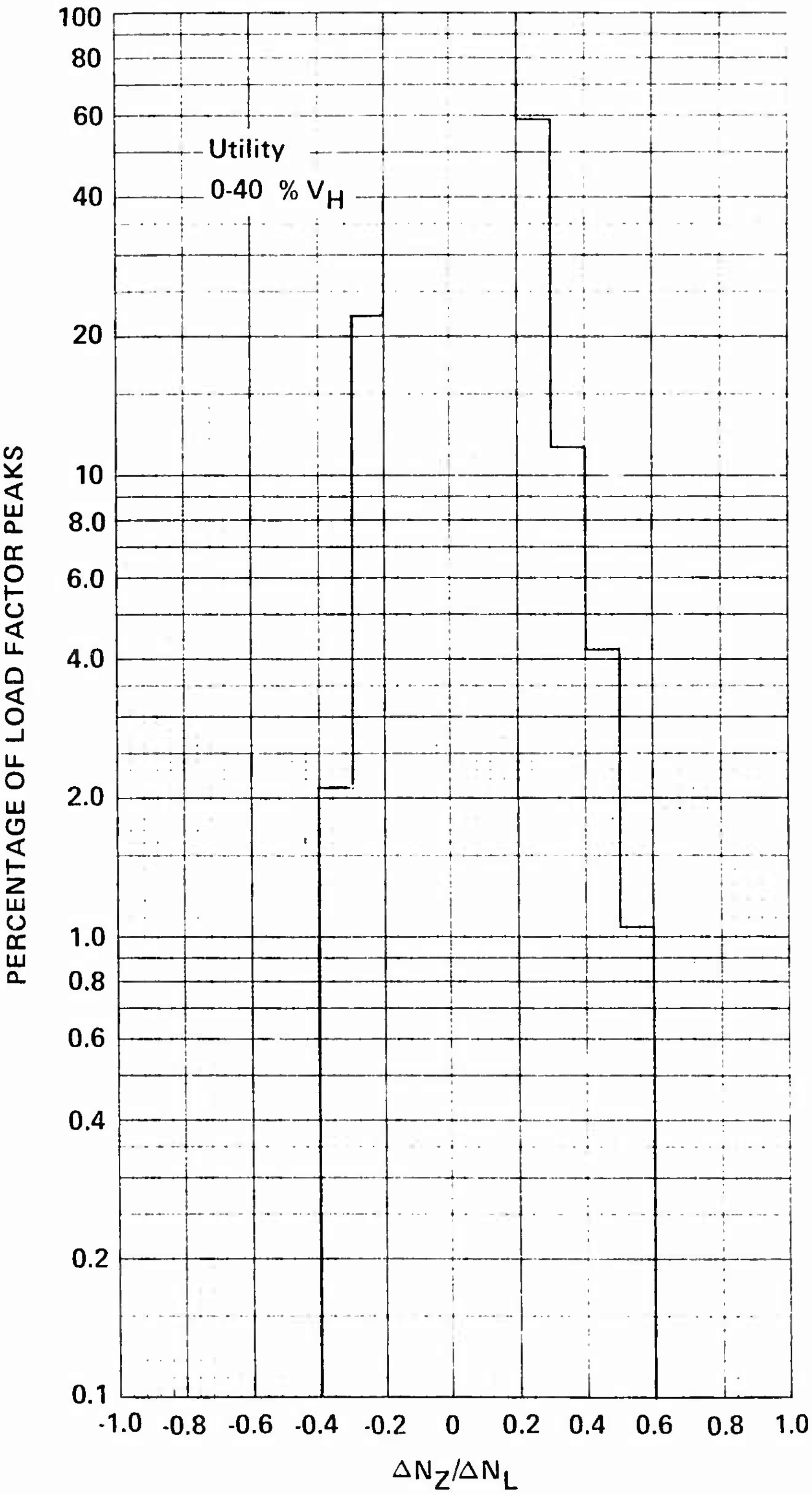


Figure 6a. Load Factor-Airspeed Distribution, Utility Type.

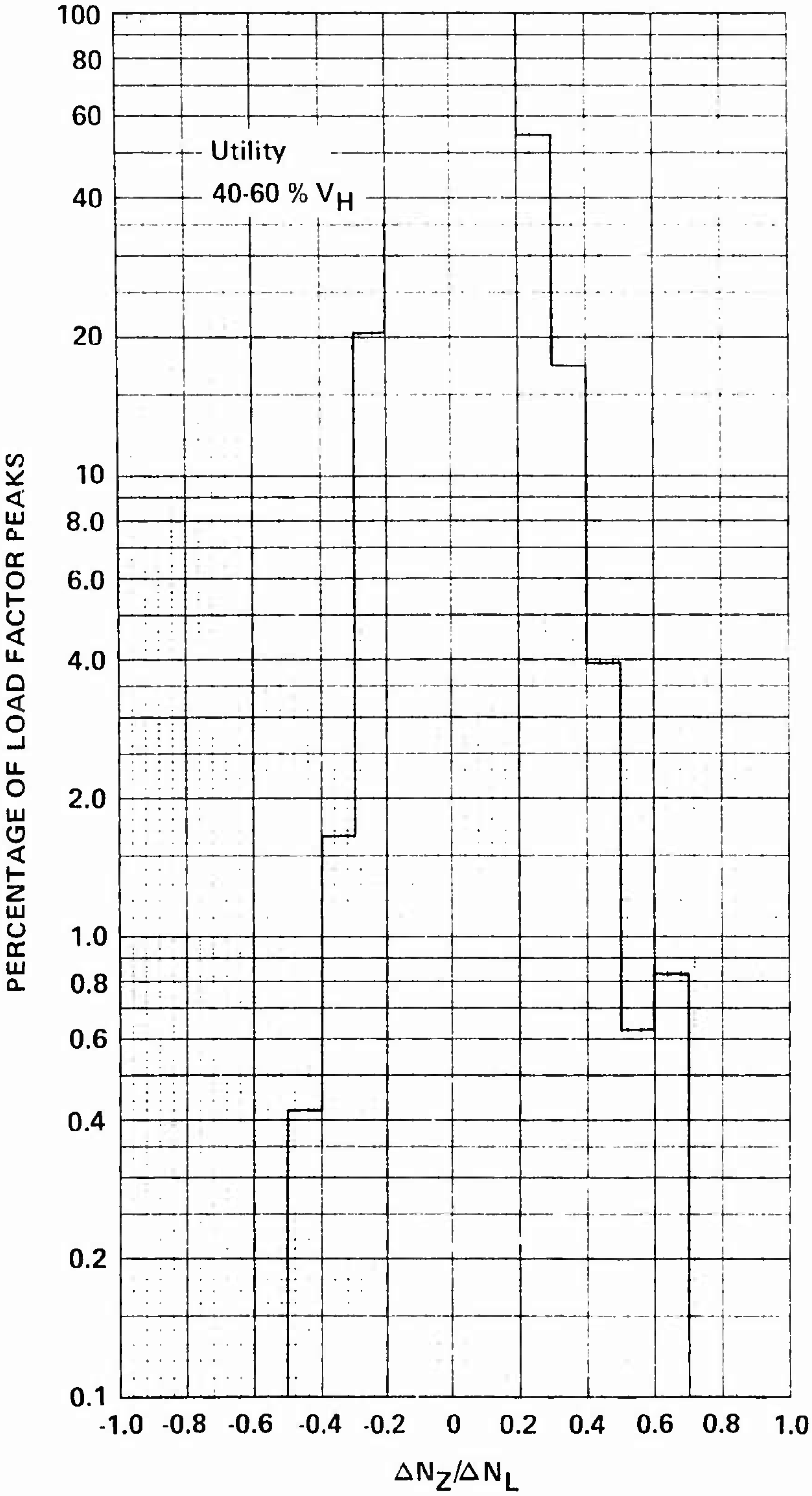


Figure 6b. Load Factor-Airspeed Distribution, Utility Type.

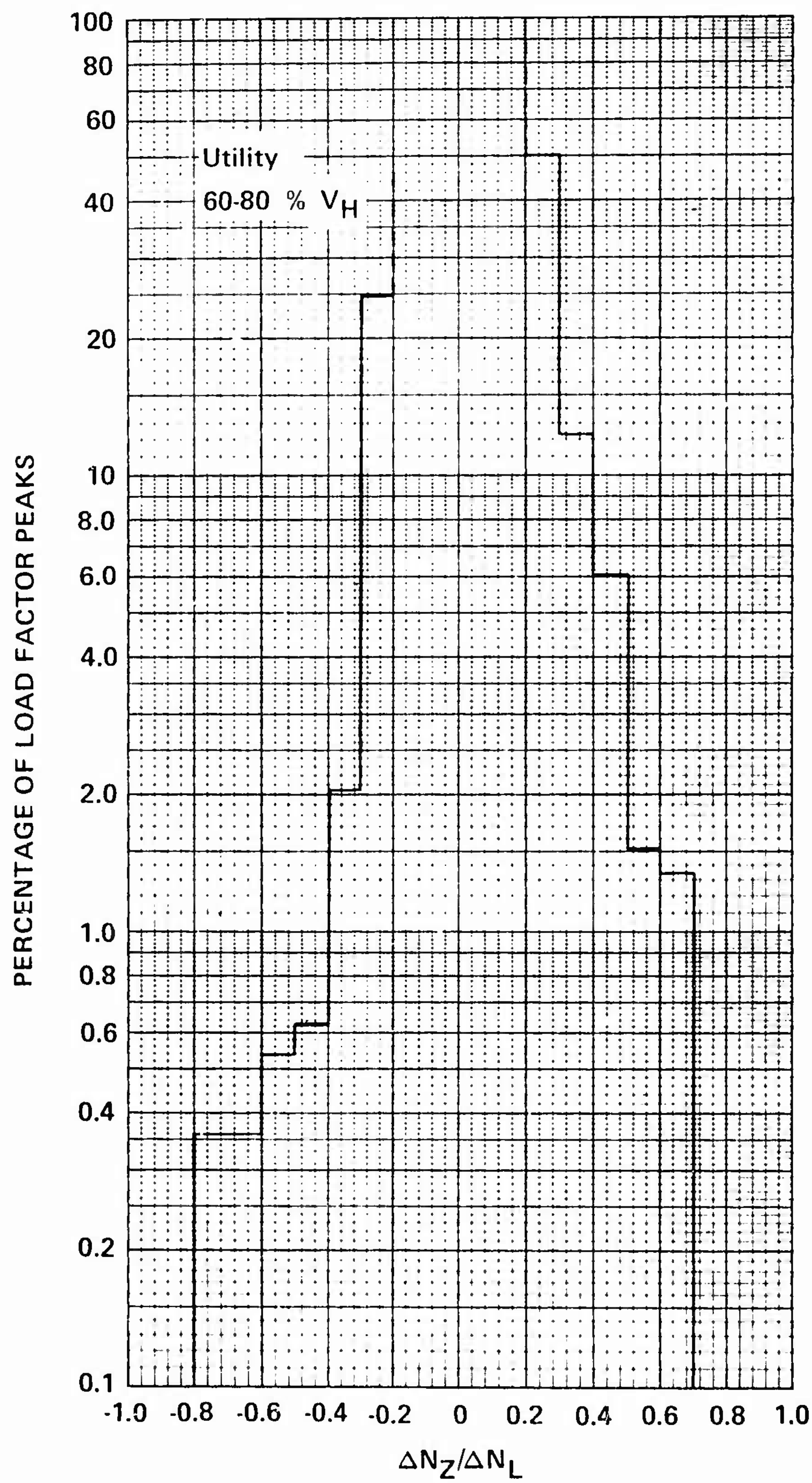


Figure 6c. Load Factor-Airspeed Distribution, Utility Type.

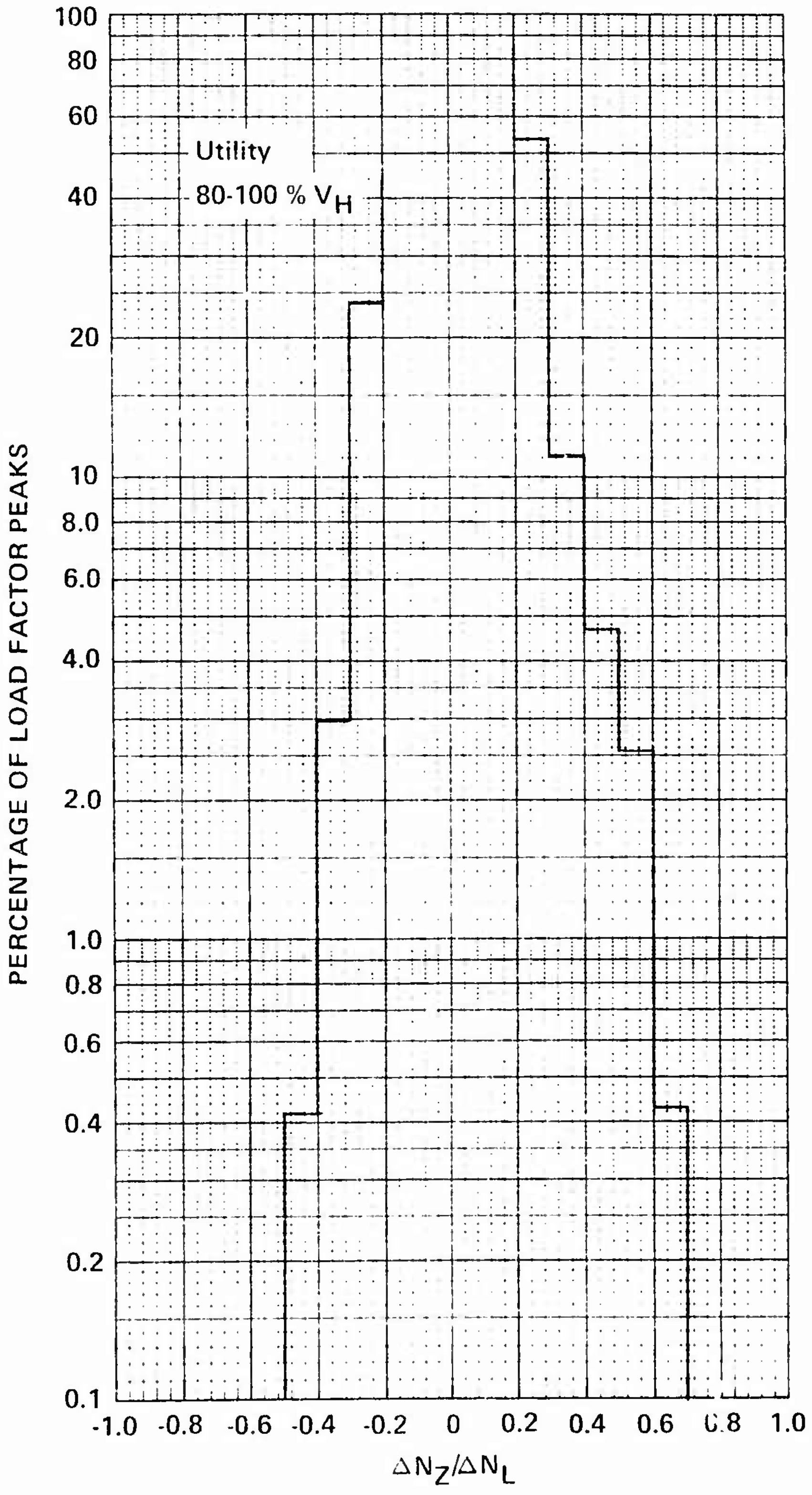


Figure 6d. Load Factor-Airspeed Distribution, Utility Type.

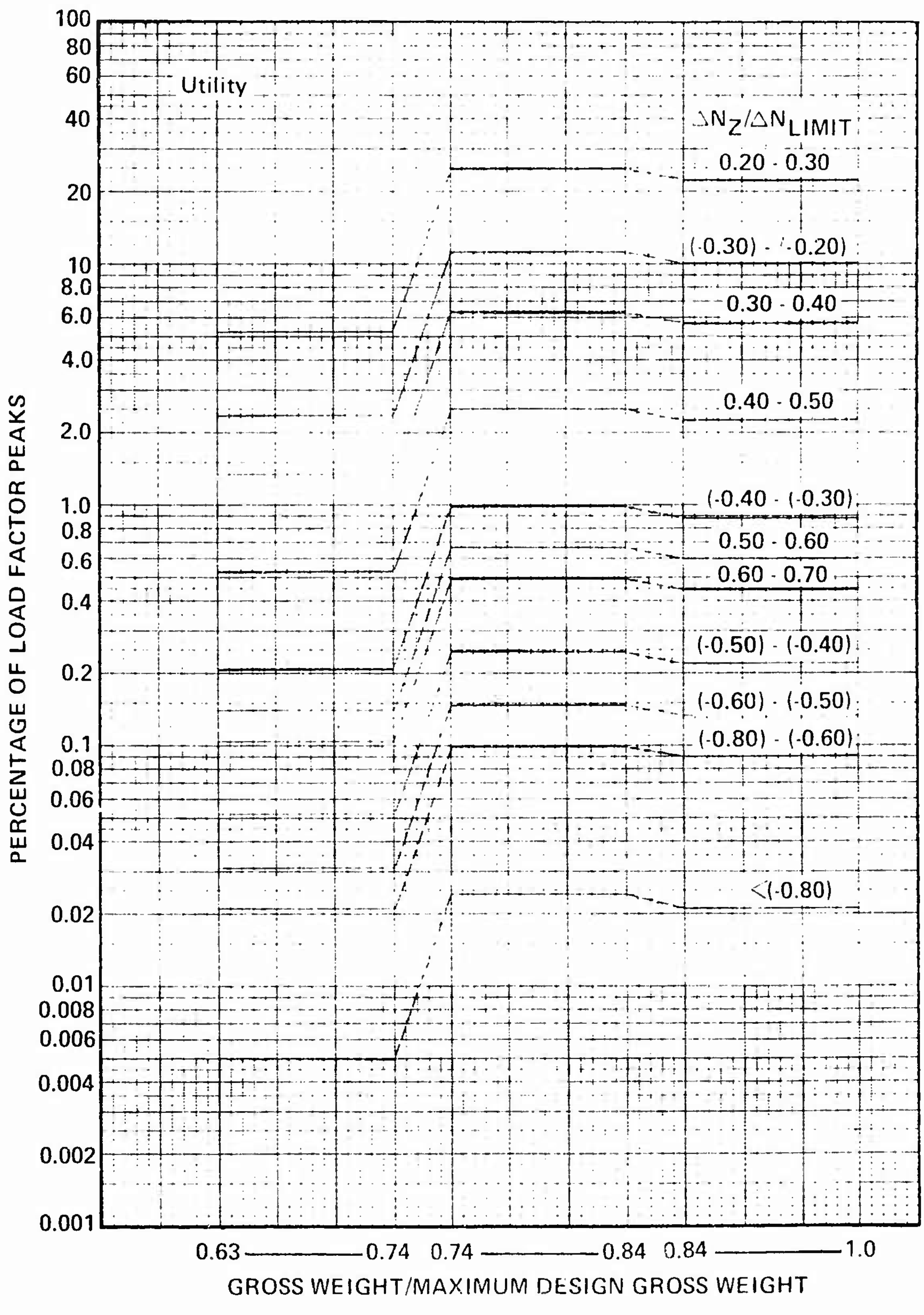


Figure 7. Load Factor-Gross Weight Distribution, Utility Type.

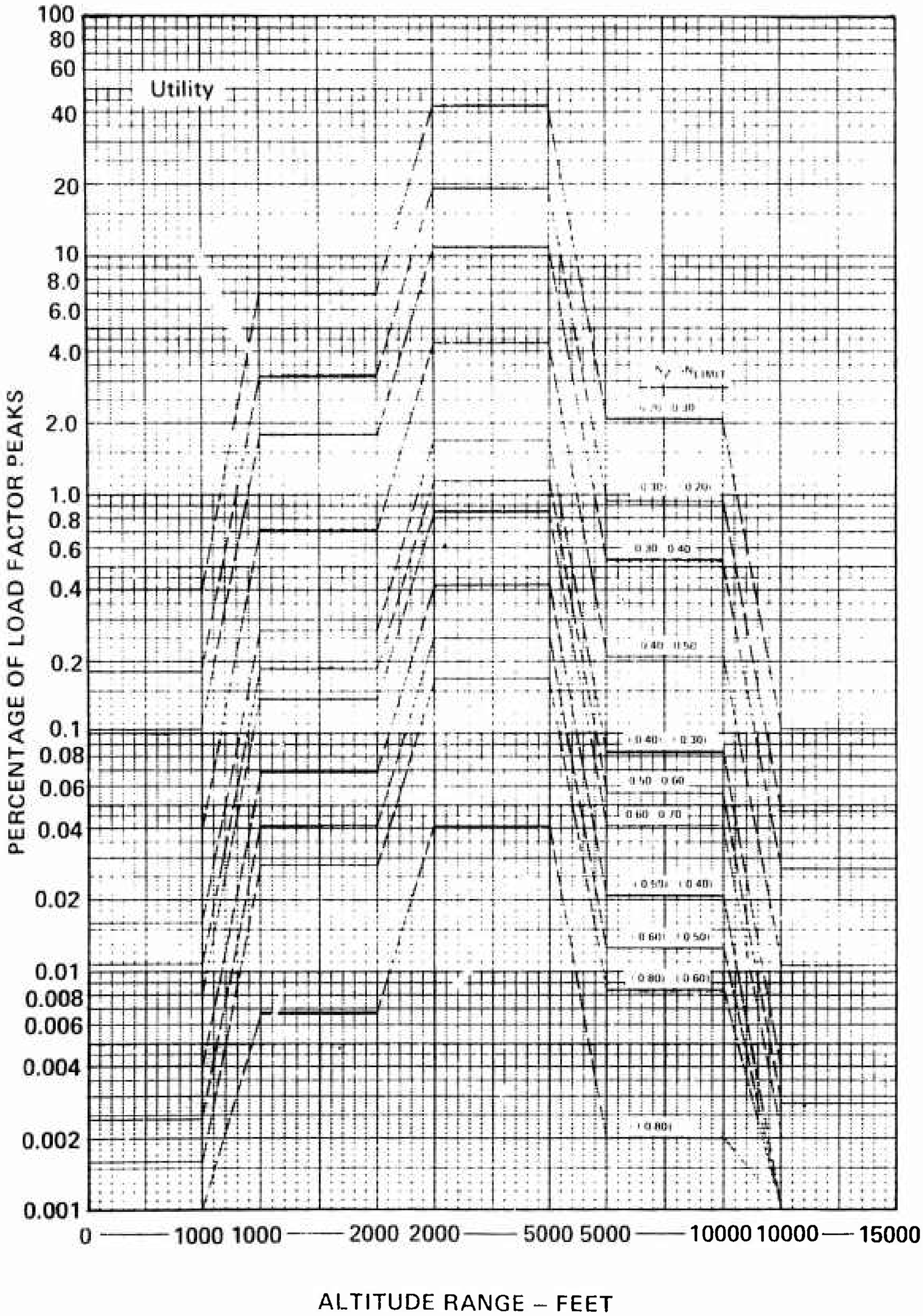


Figure 8. Load Factor-Altitude Distribution, Utility Type.

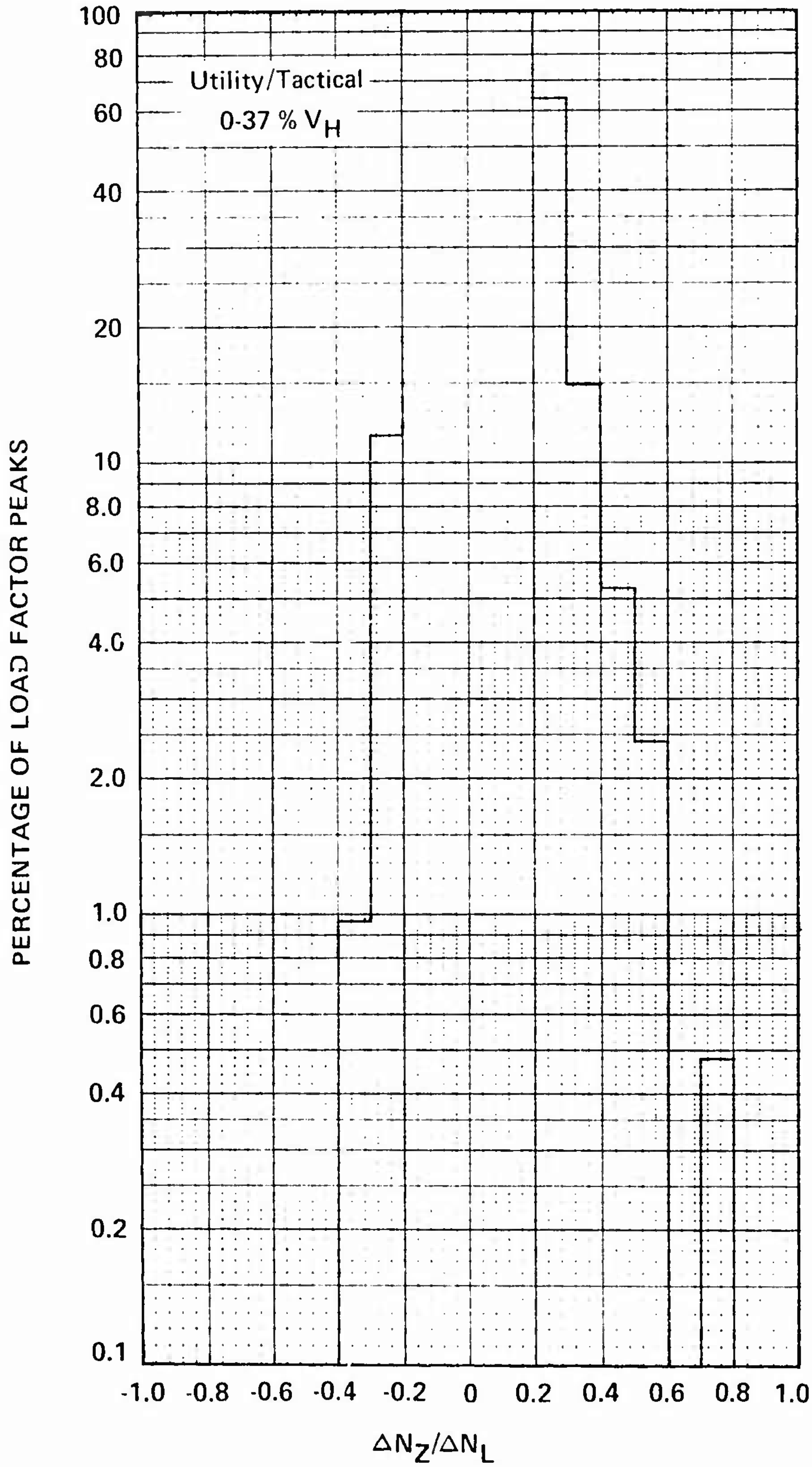


Figure 9a. Load Factor-Airspeed Distribution, Utility/Tactical Assault Type.

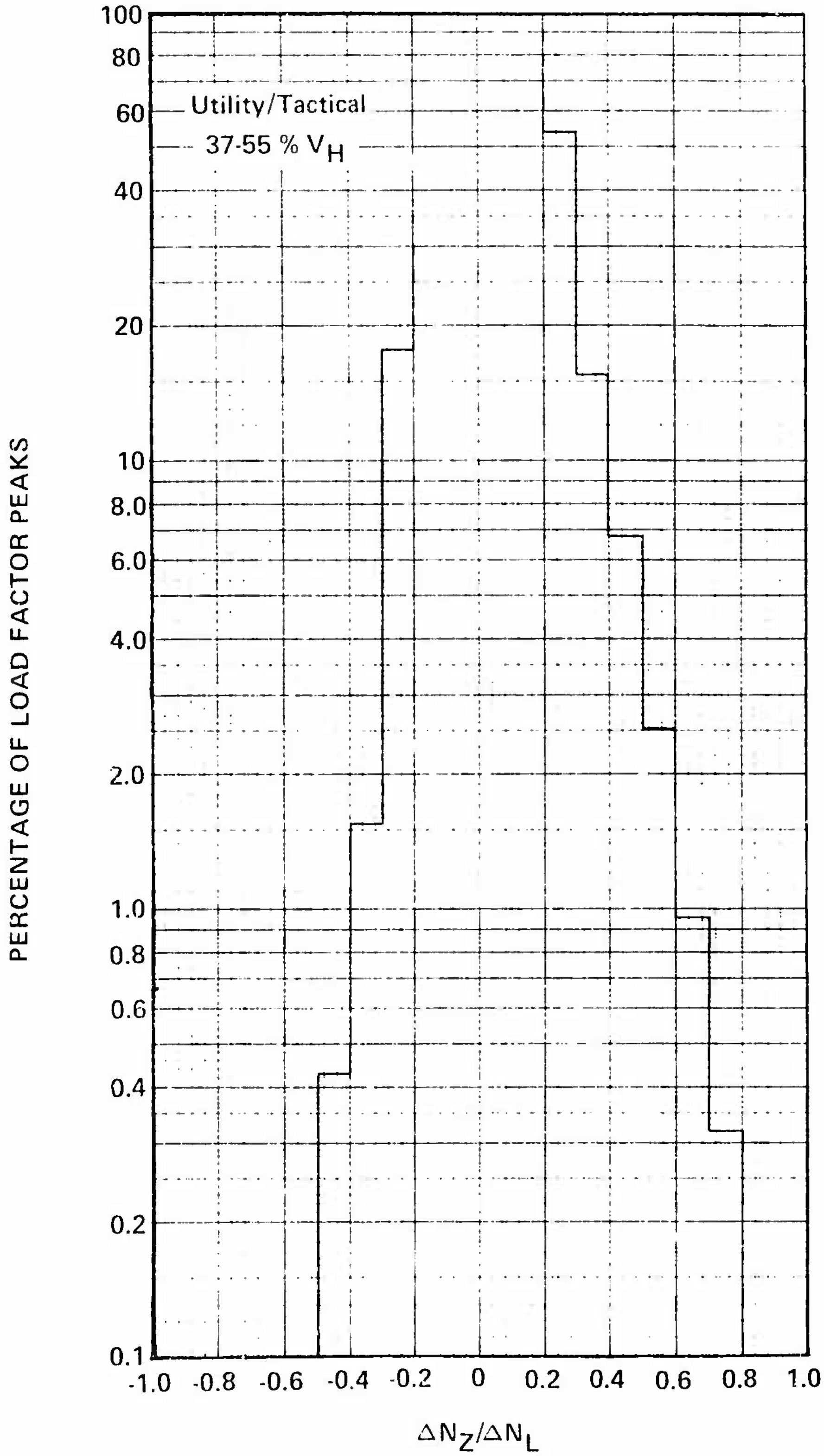


Figure 9b. Load Factor-Airspeed Distribution, Utility/Tactical Assault Type.

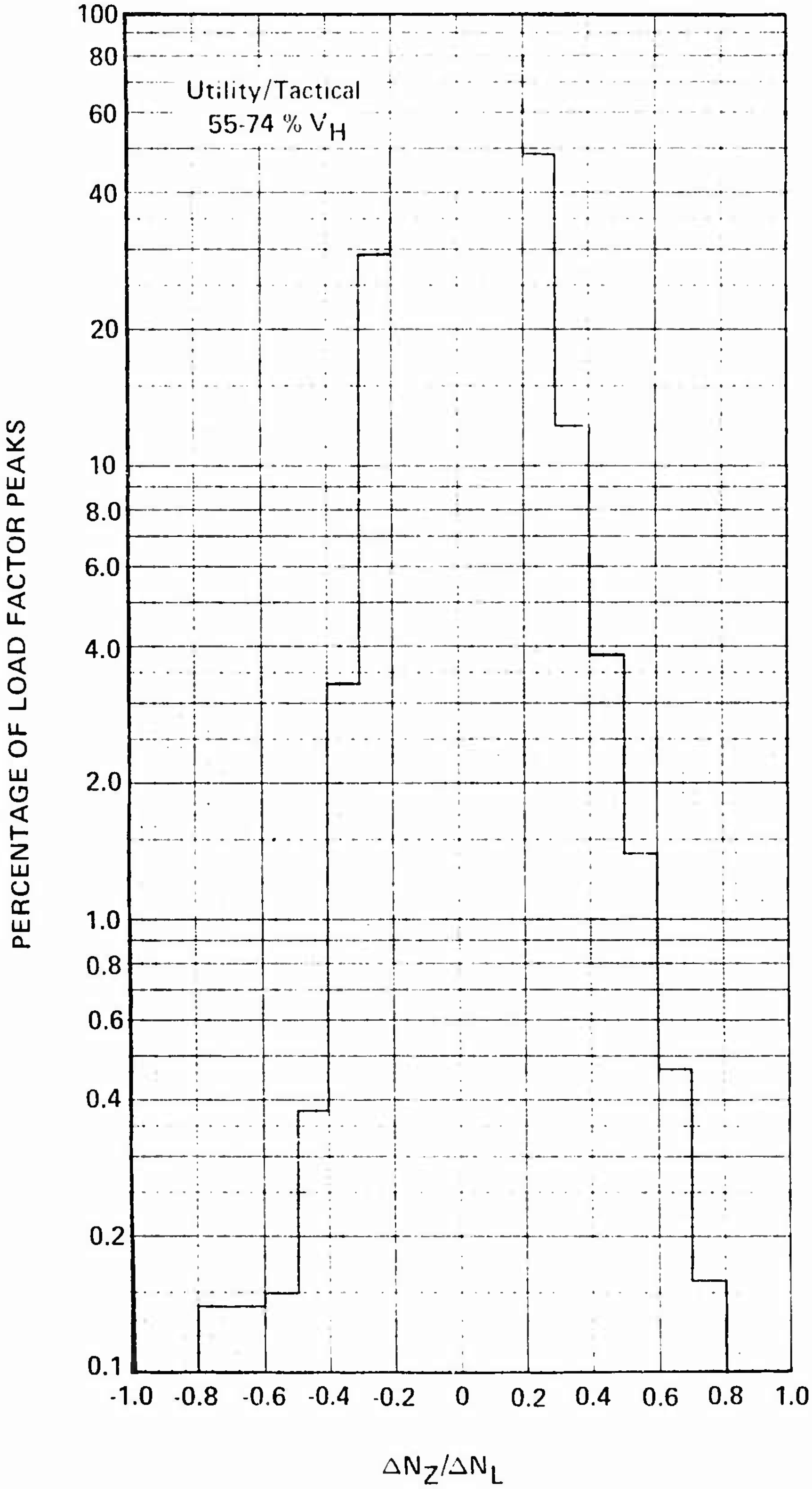


Figure 9c. Load Factor-Airspeed Distribution, Utility/Tactical Assault Type.

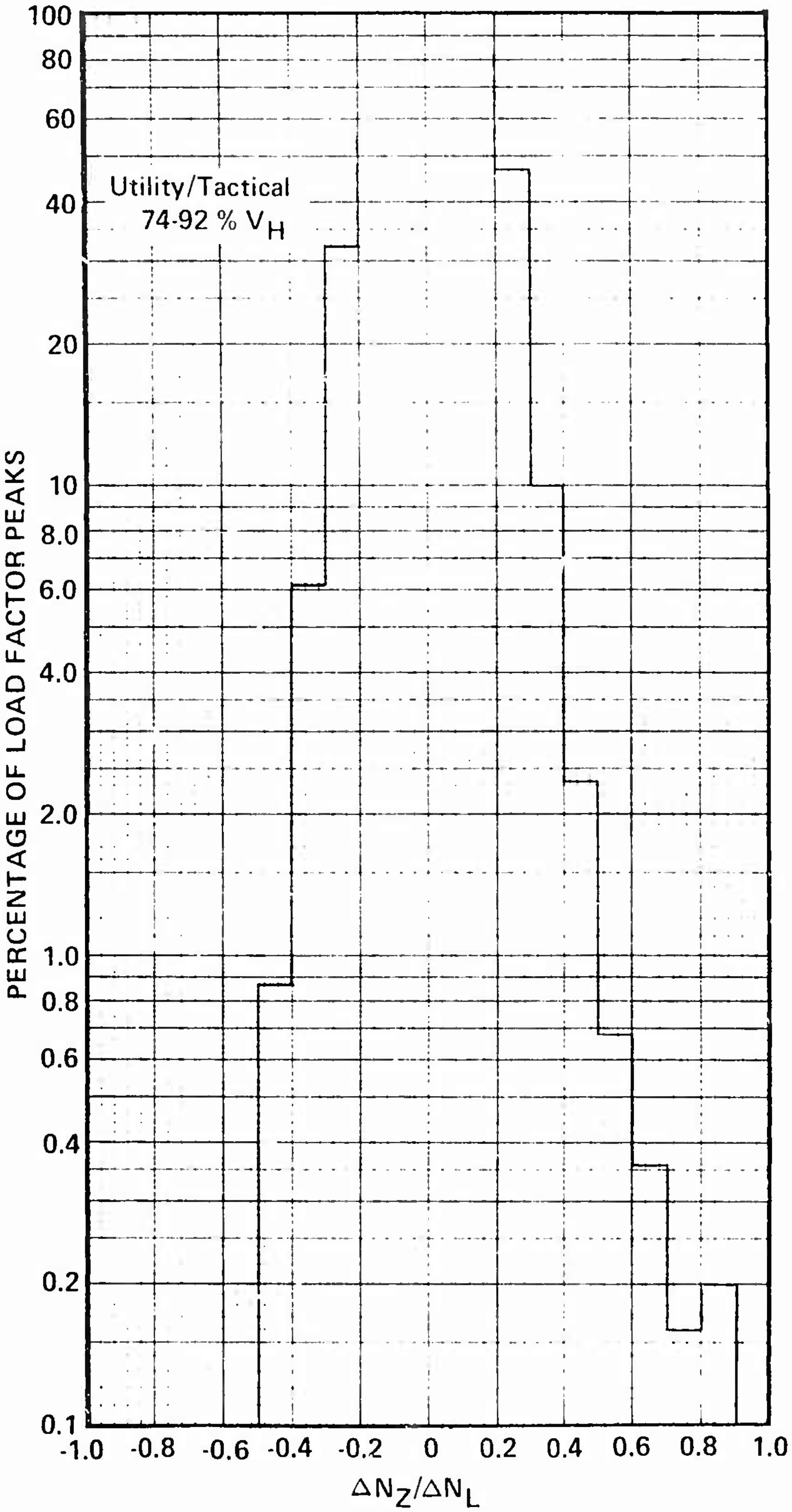


Figure 9d. Load Factor-Airspeed Distribution, Utility/Tactical Assault Type.

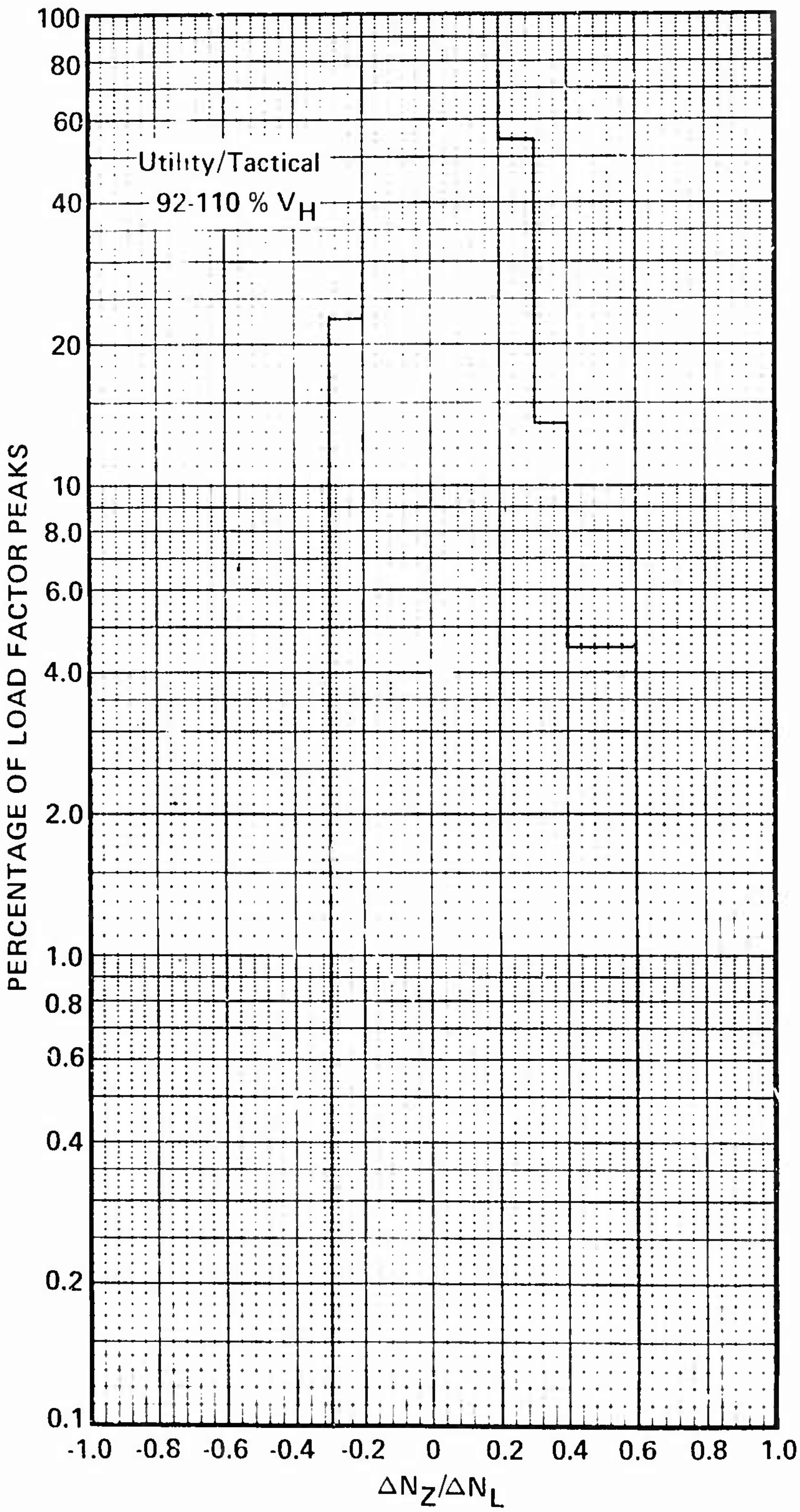


Figure 9e. Load Factor-Airspeed Distribution, Utility/Tactical Assault Type.

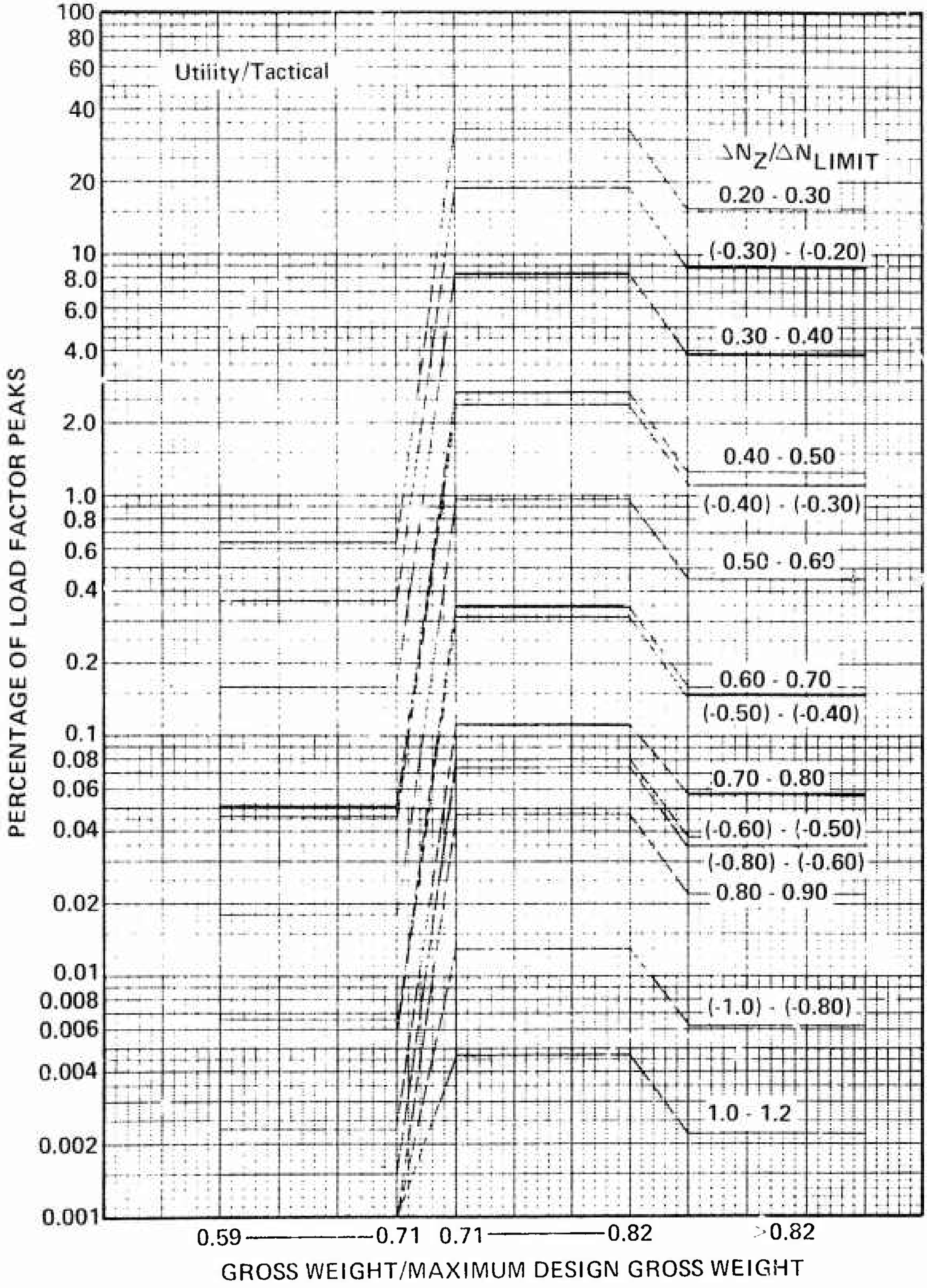


Figure 10. Load Factor-Gross Weight Distribution, Utility/Tactical Assault Type.

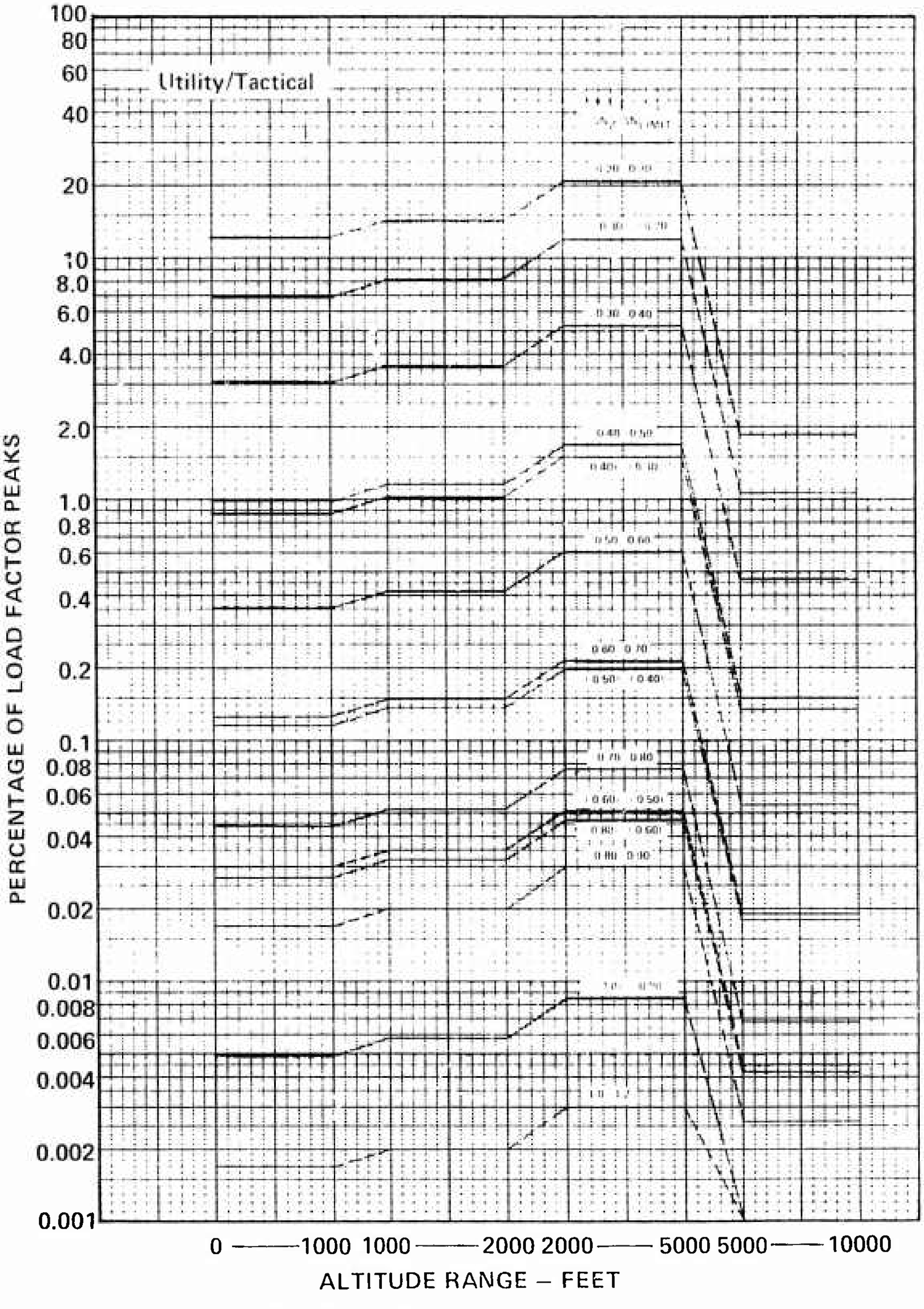


Figure 11. Load Factor-Altitude Distribution, Utility/Tactical Assault Type.

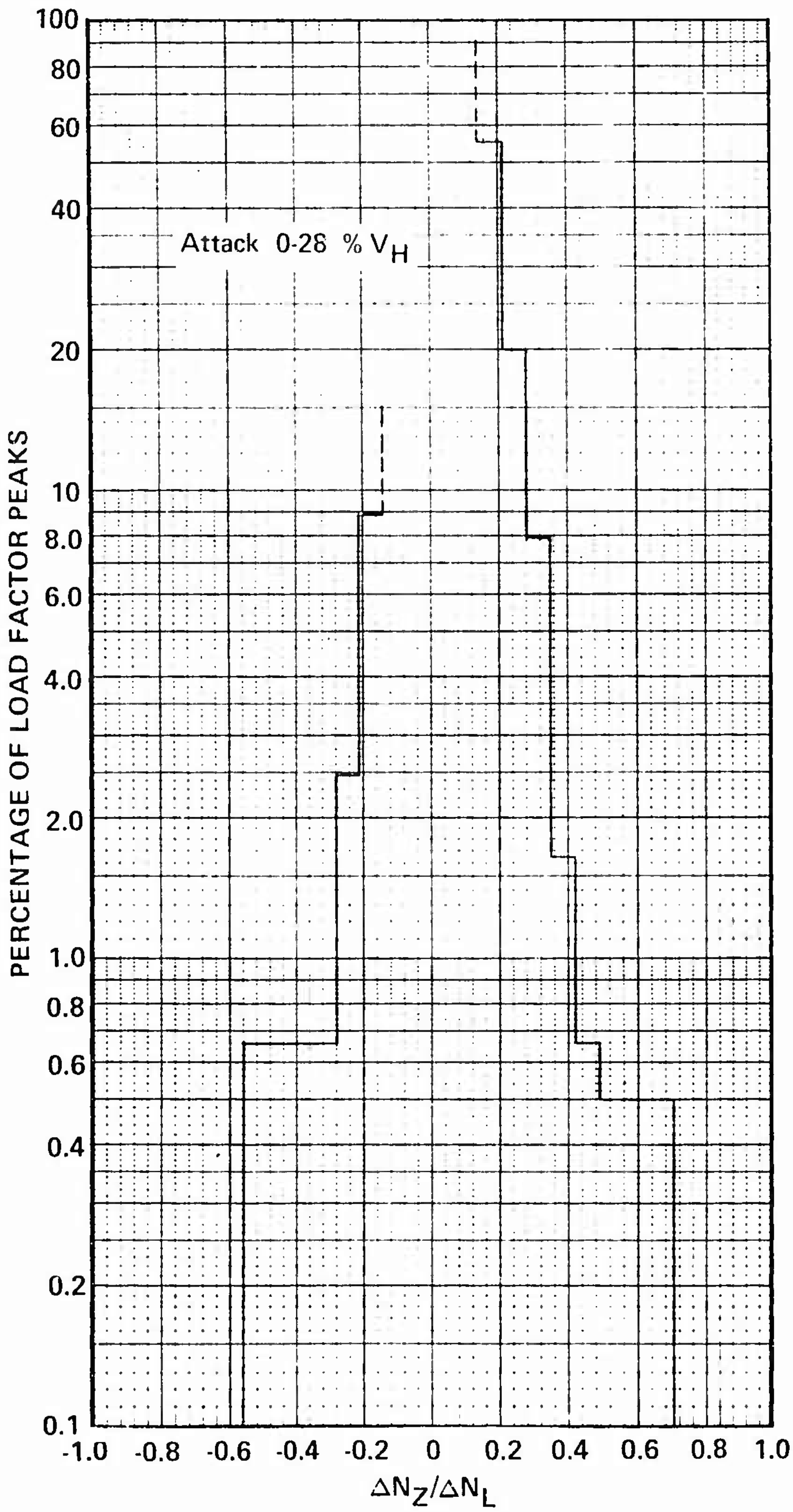


Figure 12a. Load Factor-Airspeed Distribution, Attack Type.

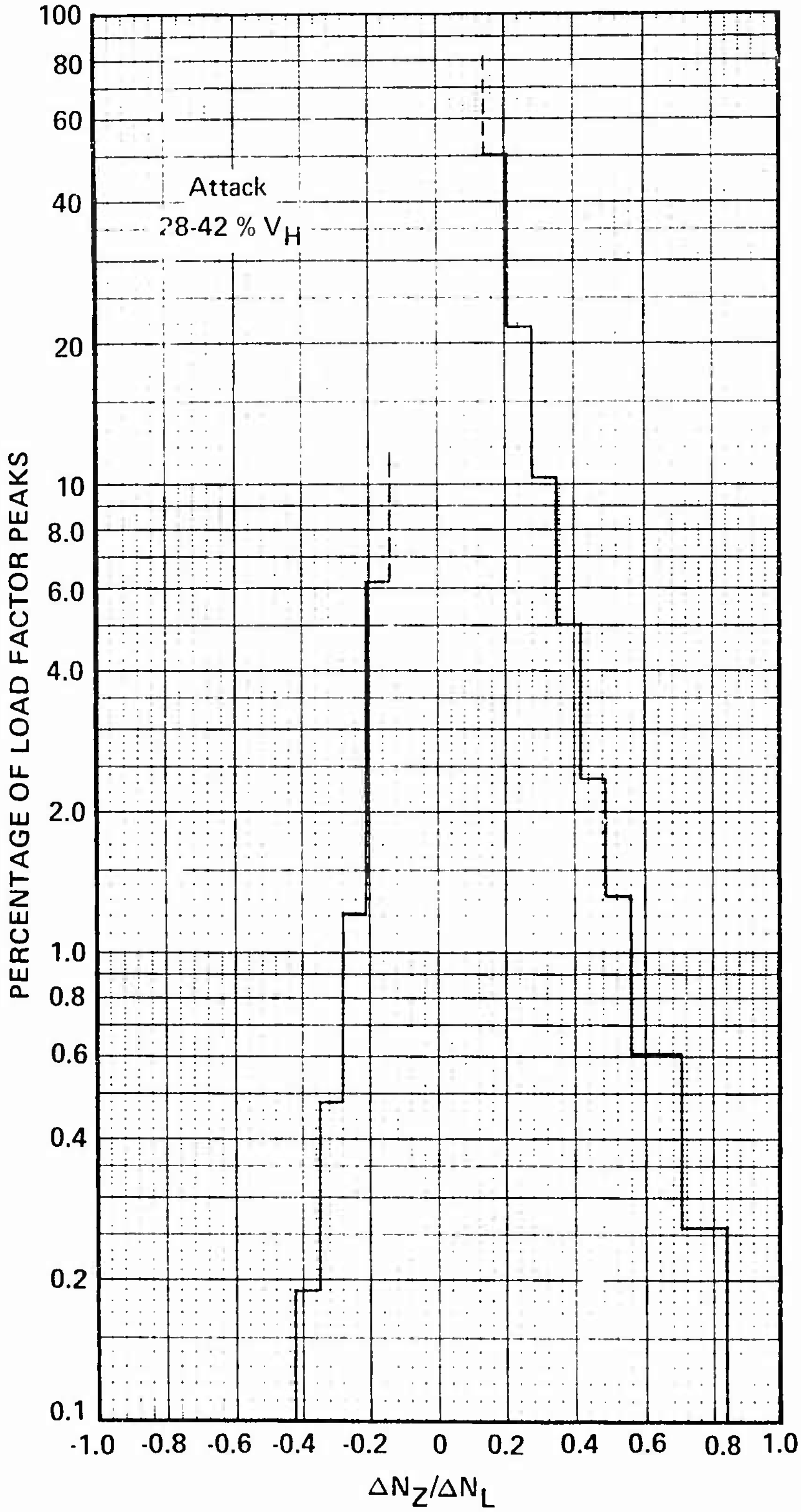


Figure 12b. Load Factor-Airspeed Distribution, Attack Type.

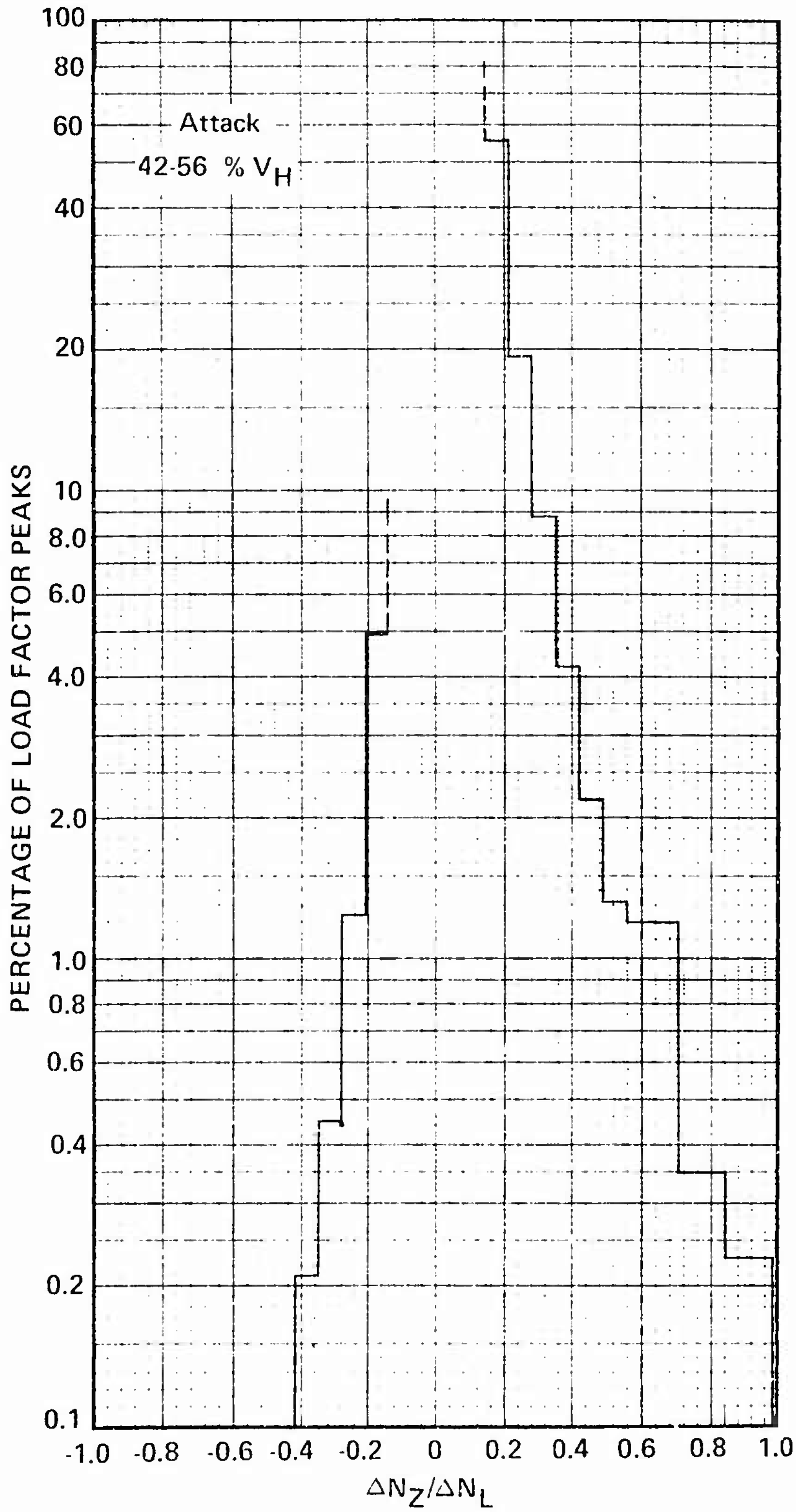


Figure 12c. Load Factor-Airspeed Distribution, Attack Type.

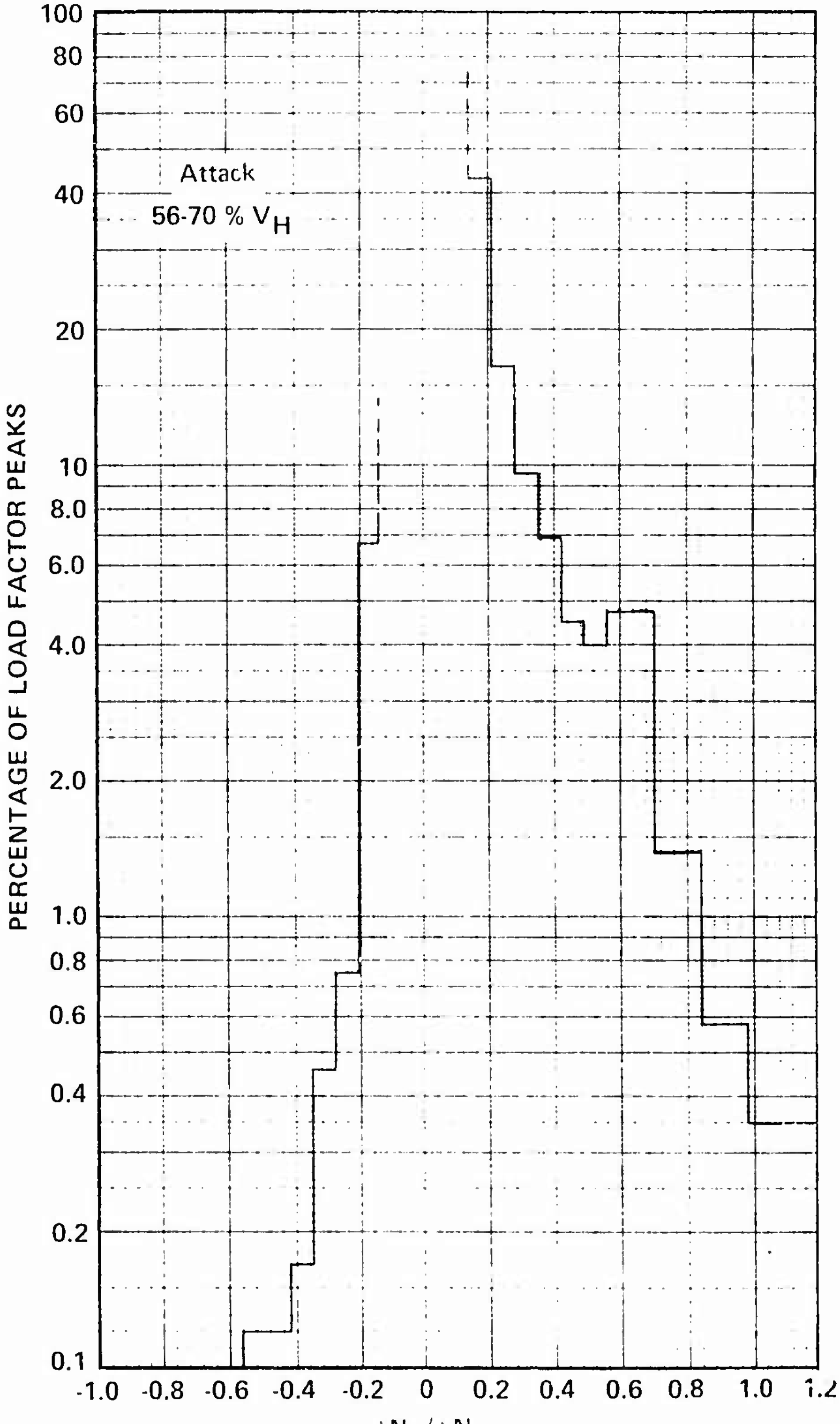


Figure 12d. Load Factor-Airspeed Distribution, Attack Type.

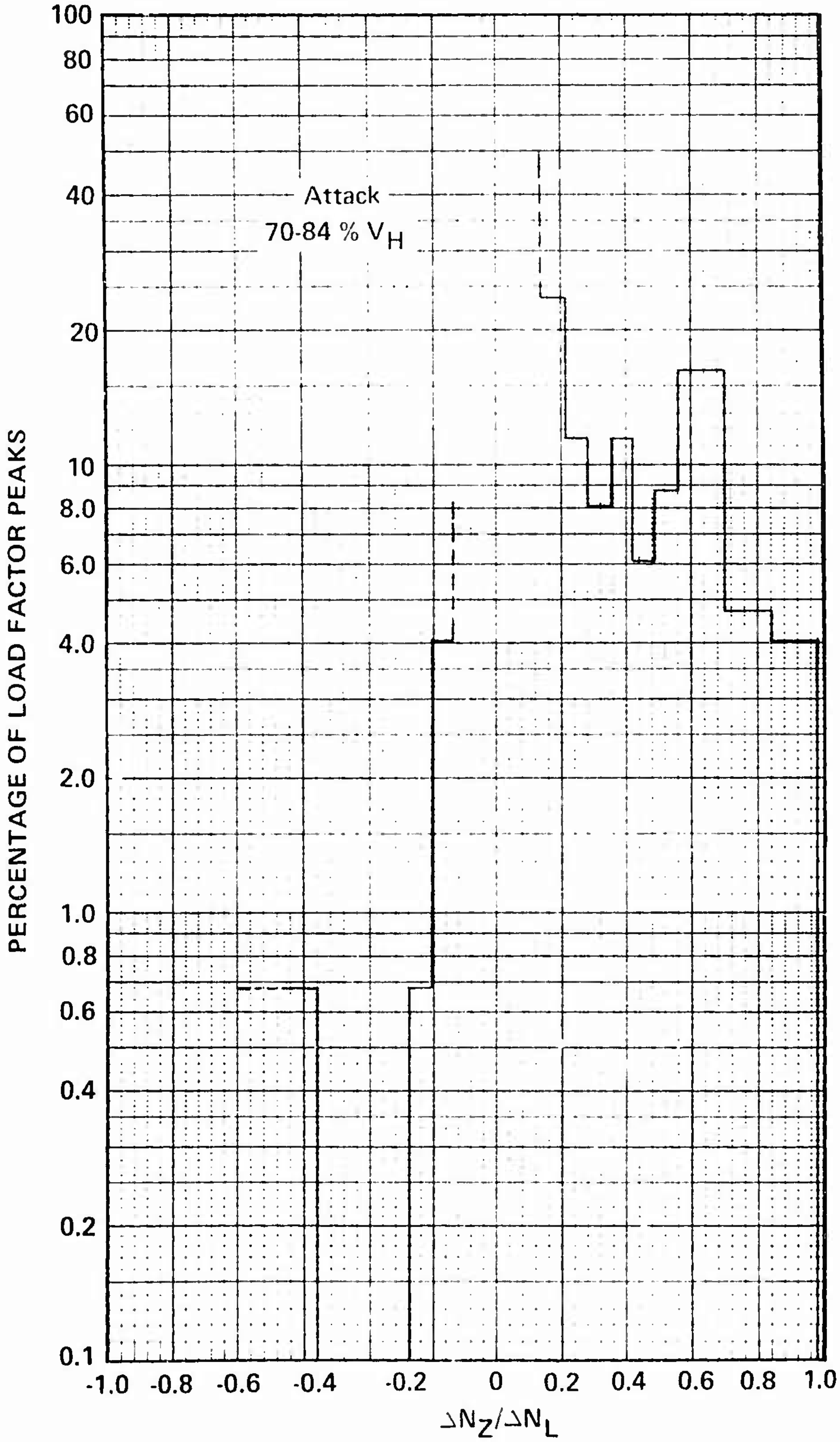


Figure 12e. Load Factor-Airspeed Distribution, Attack Type.

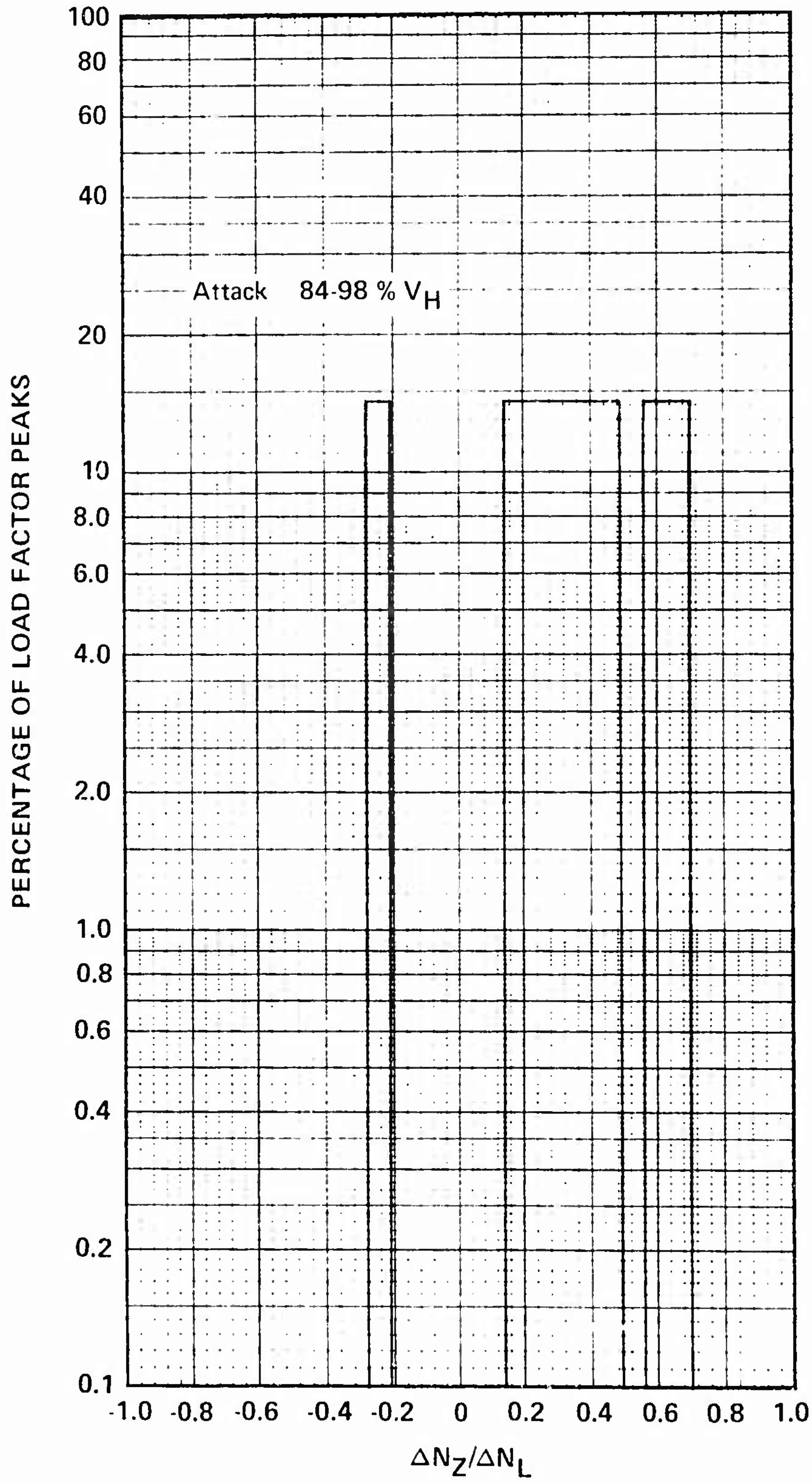


Figure 12f. Load Factor-Airspeed Distribution, Attack Type.

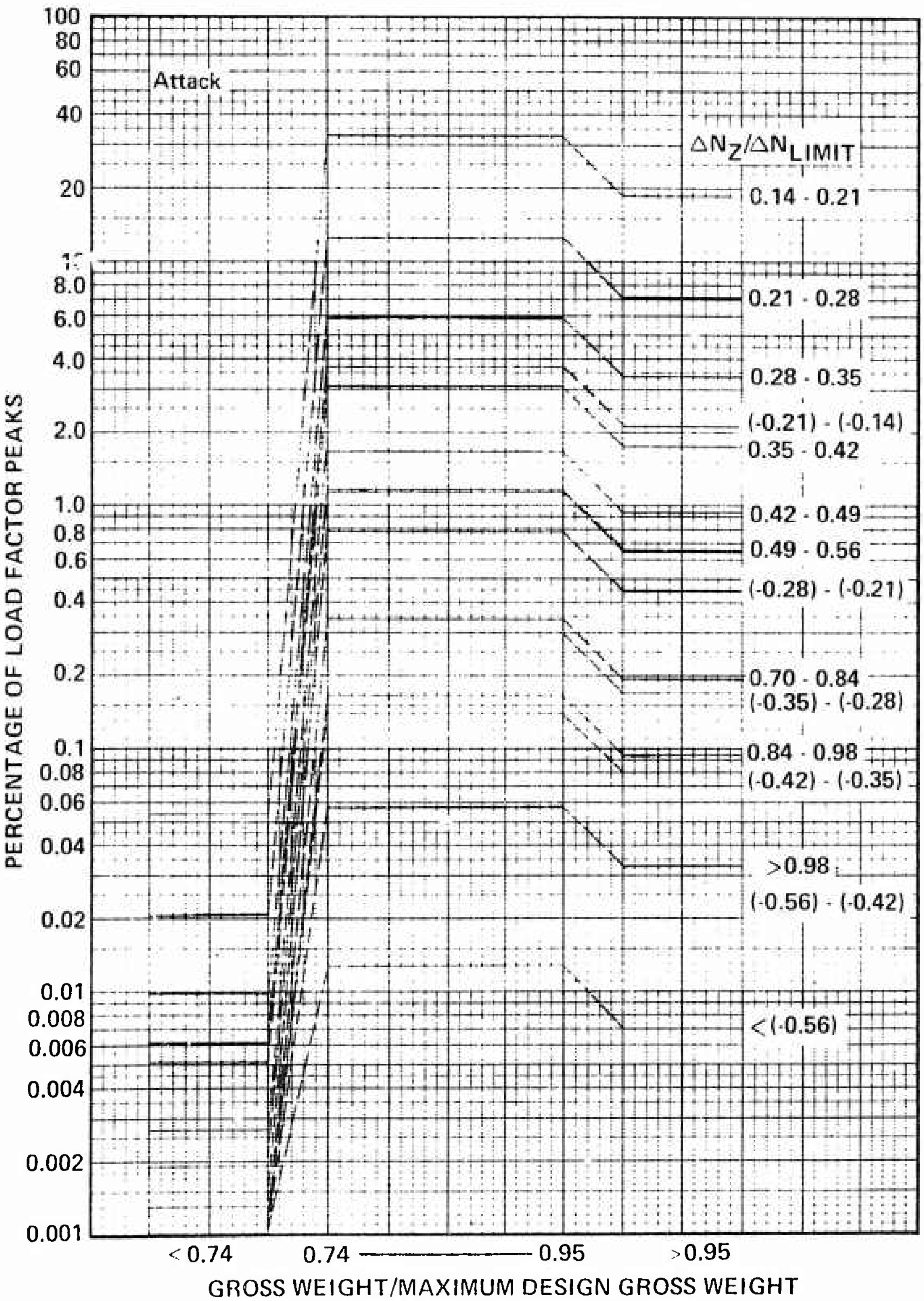
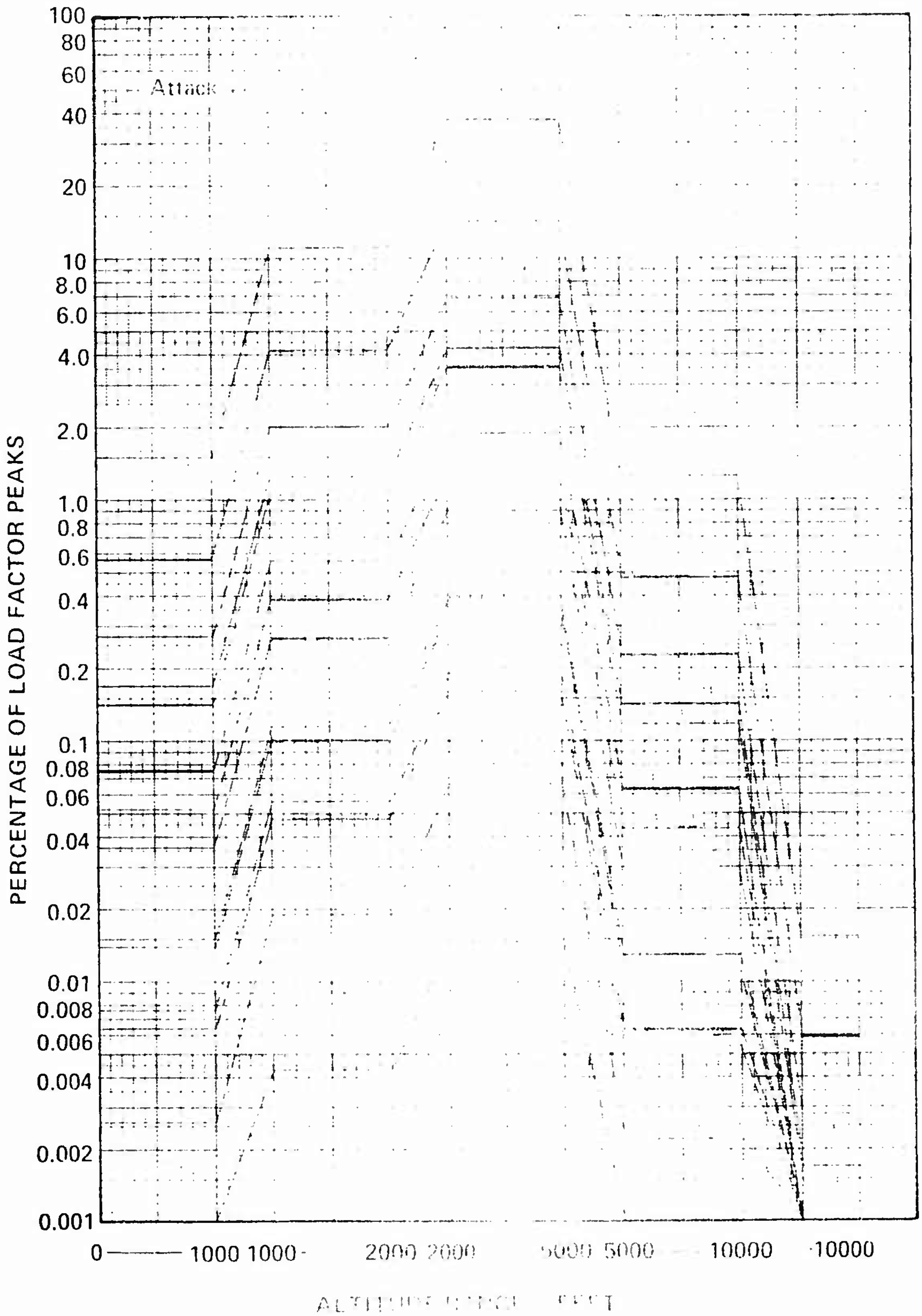


Figure 13. Load Factor-Gross Weight Distribution, Attack Type.



100
80
60
40
20
10
8.0
6.0
4.0
2.0
1.0
0.8
0.6
0.4
0.2
0.1
0.08
0.06
0.04
0.02
0.01
0.008
0.006
0.004
0.002
0.001
Attack
PERCENTAGE OF LOAD FACTOR PEAKS
0
1000 1000
2000 2000
5000 5000
10000
10000

Figure 1

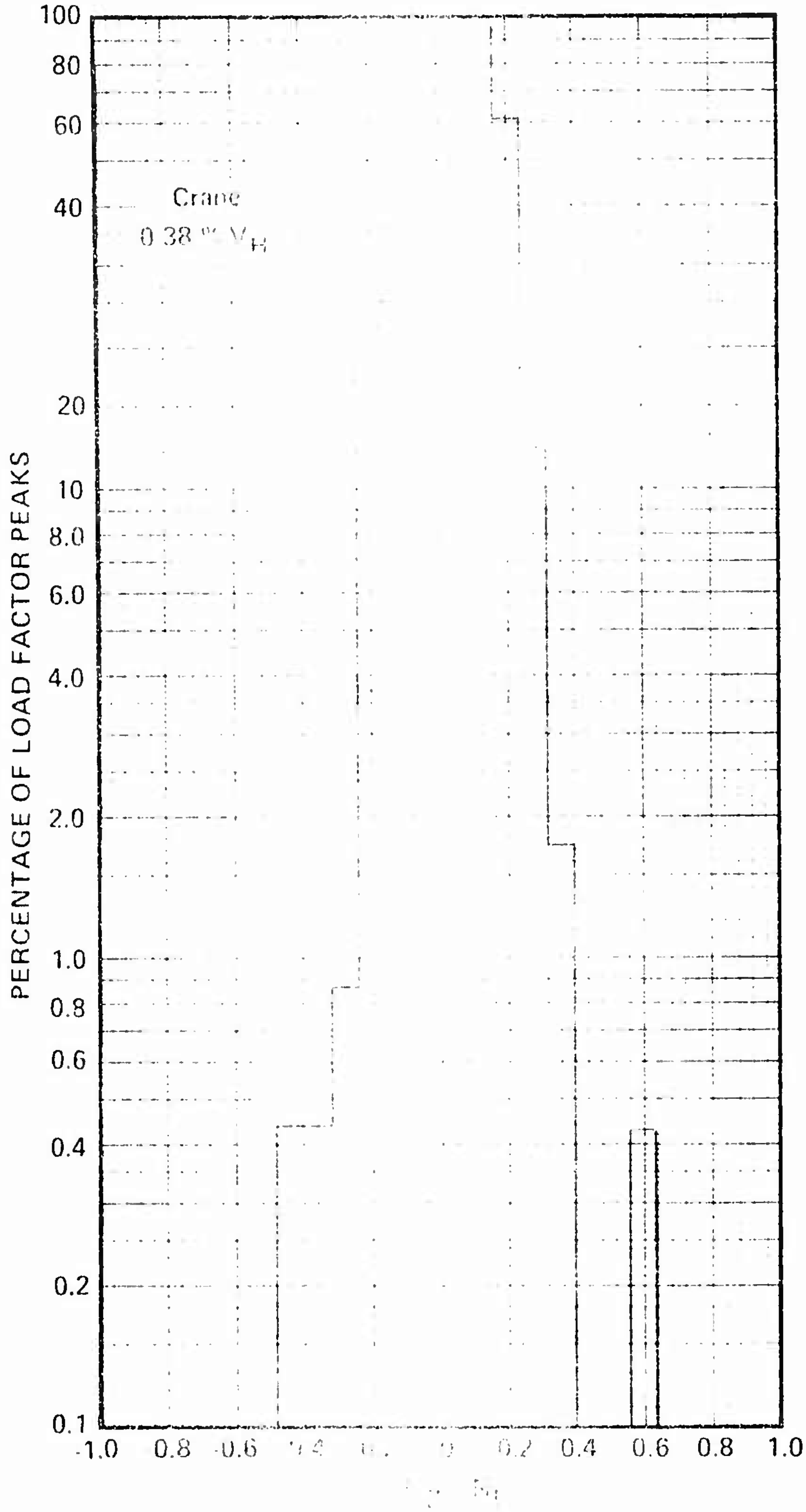


Figure 15a. Loa[illegible] [illegible]orrelation, Crane Type.

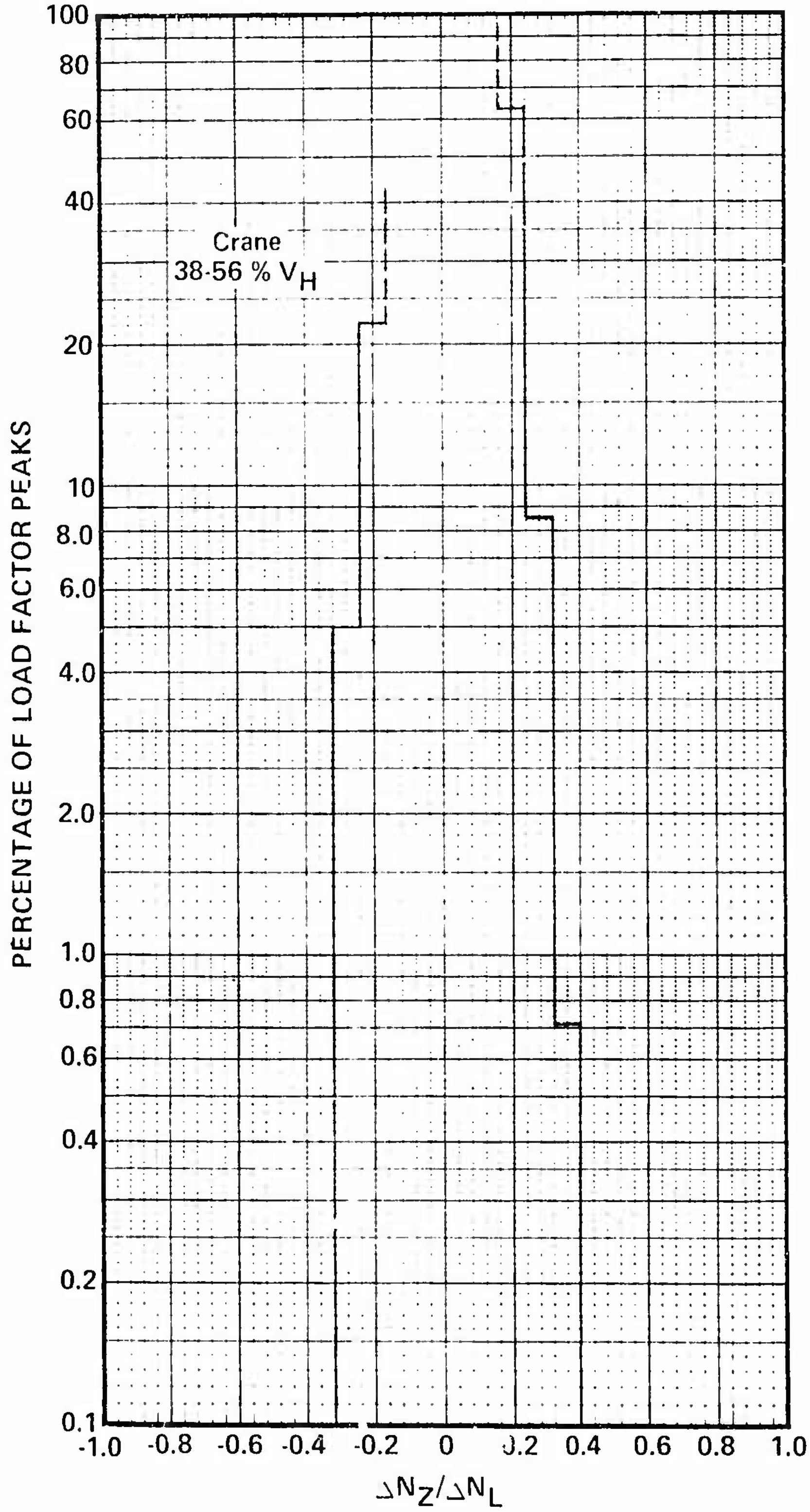


Figure 15b. Load Factor-Airspeed Distribution, Crane Type.

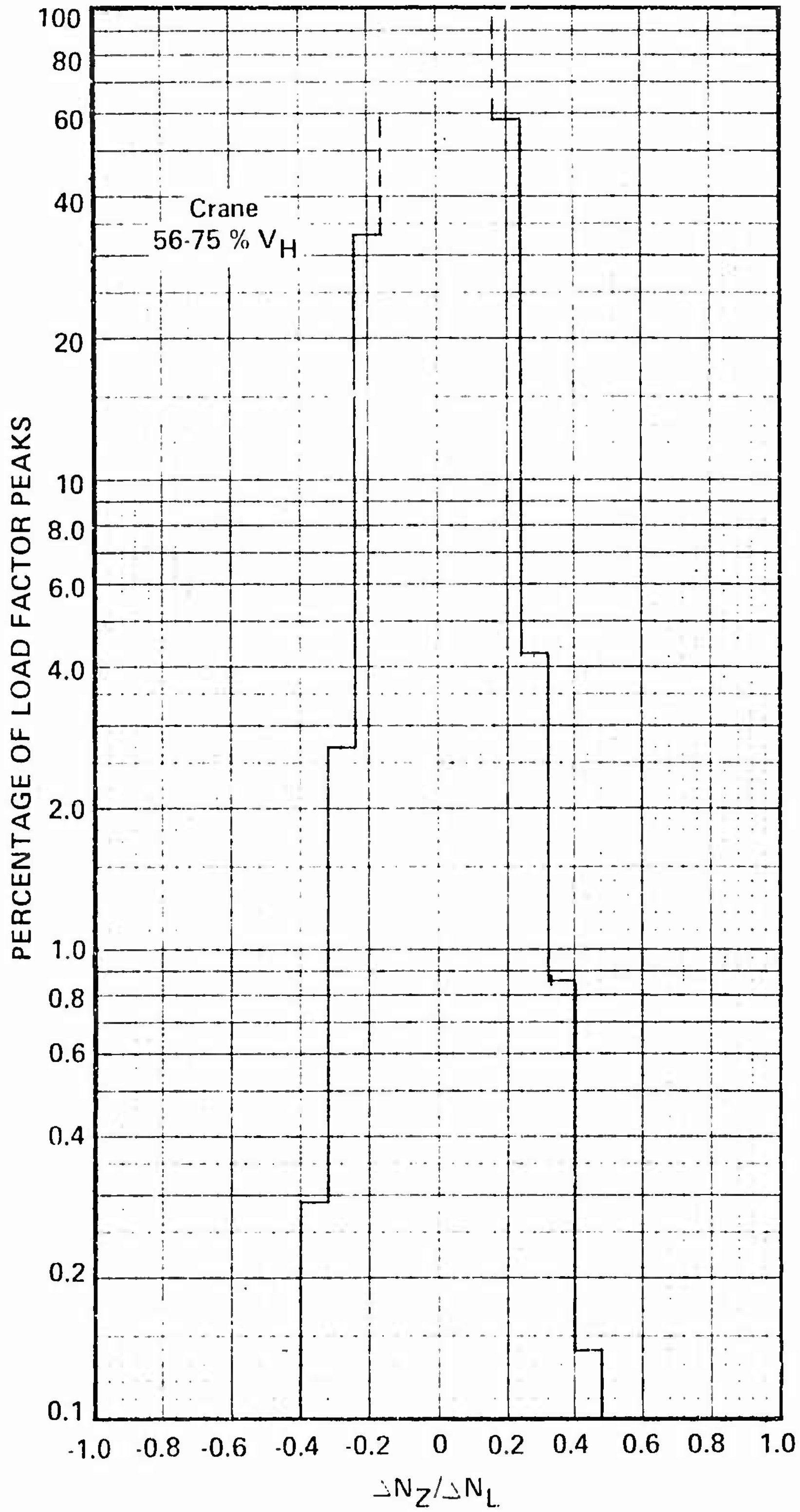


Figure 15c. Load Factor-Airspeed Distribution, Crane Type.

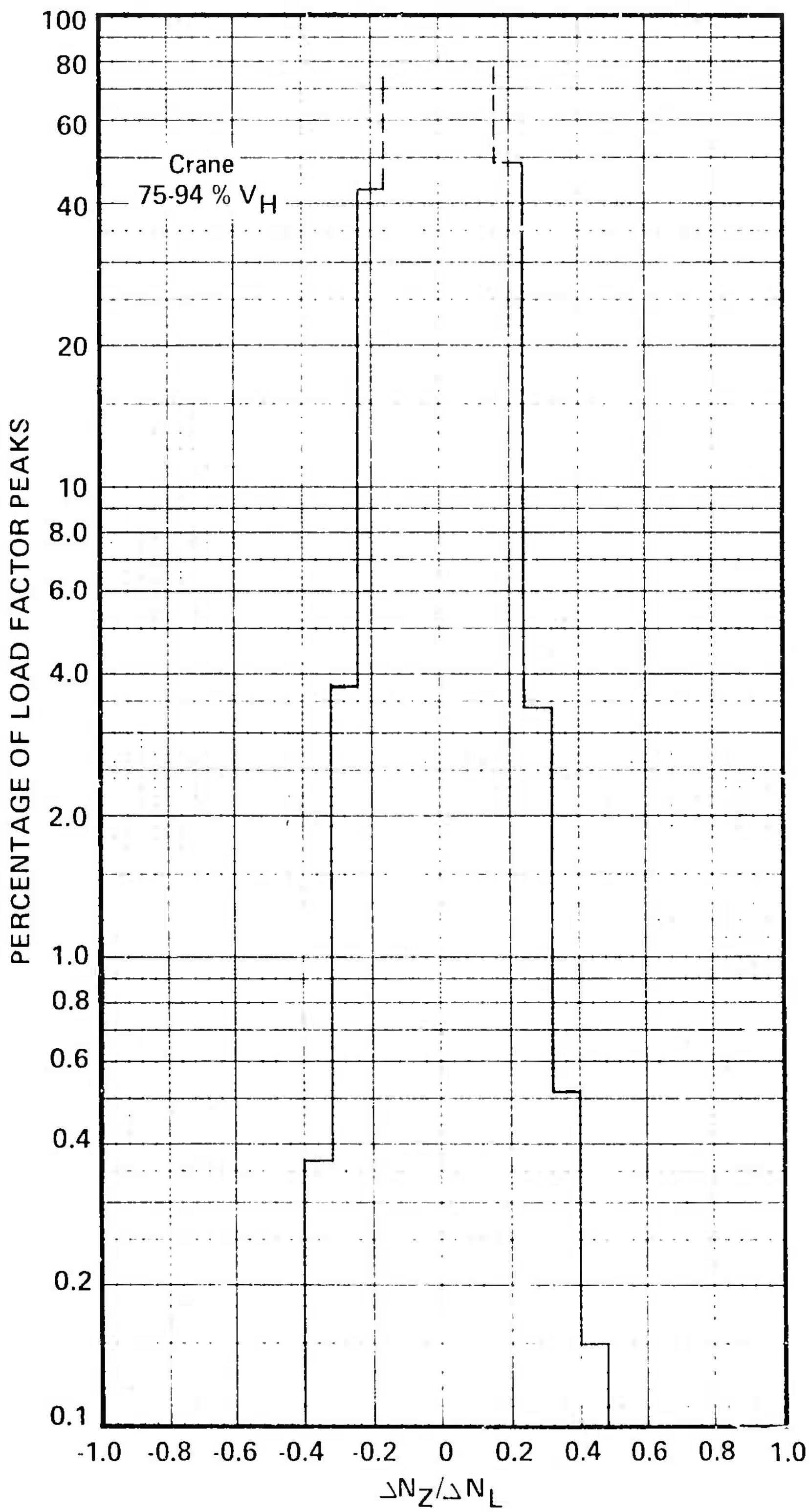


Figure 15d. Load Factor-Airspeed Distribution, Crane Type.

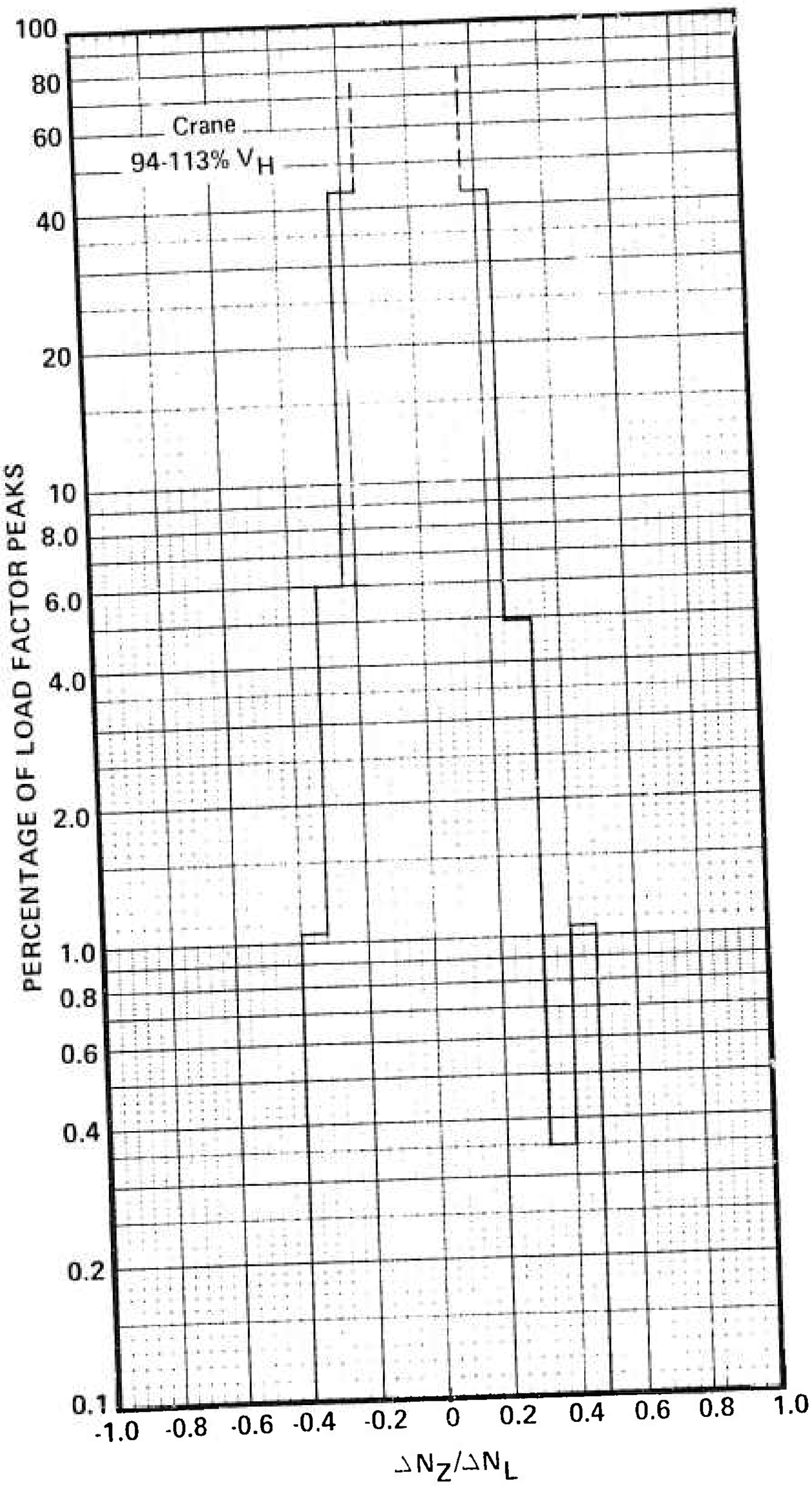


Figure 15e. Load Factor-Airspeed Distribution, Crane Type.

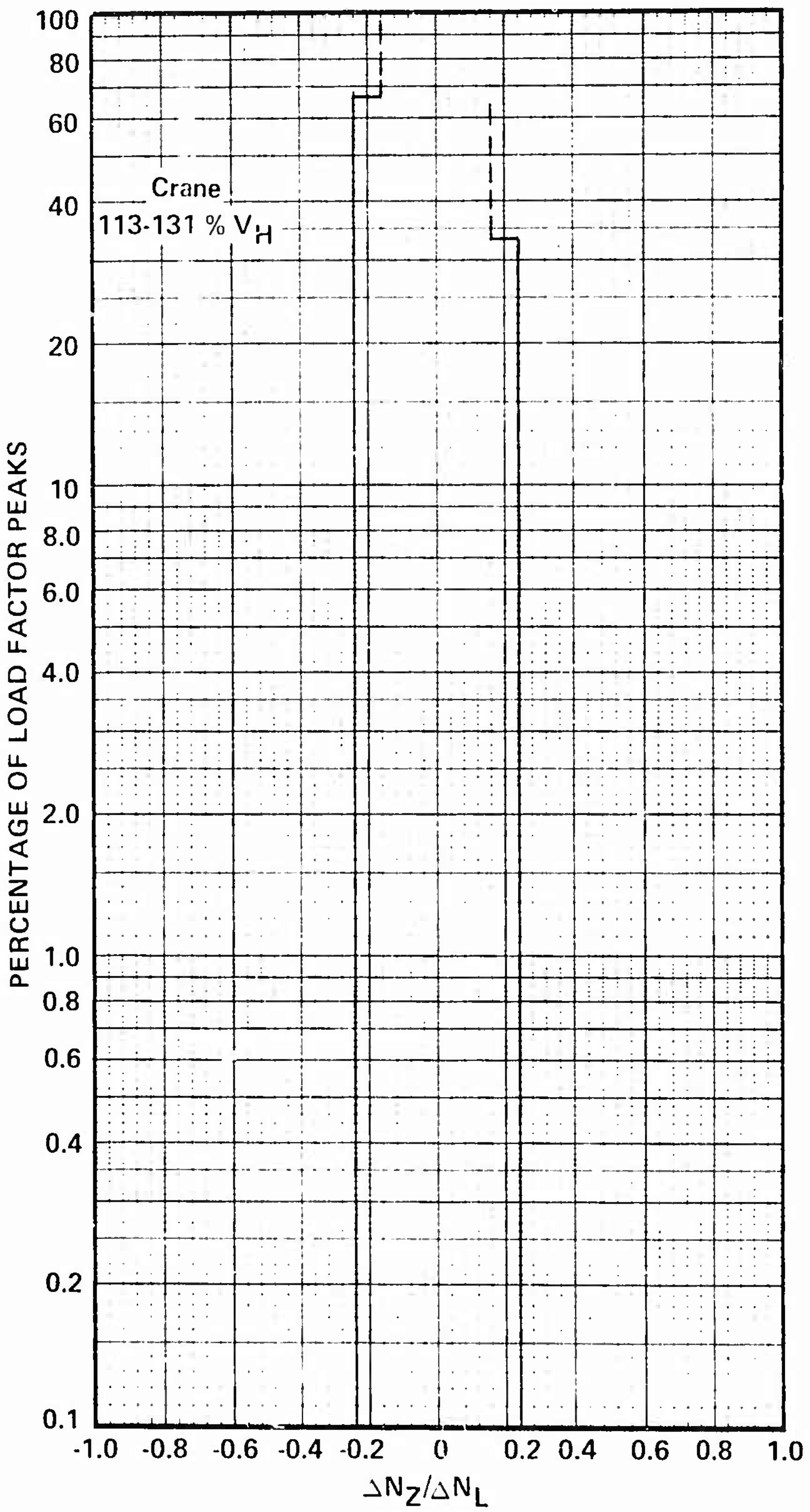


Figure 15f. Load Factor-Airspeed Distribution, Crane Type.

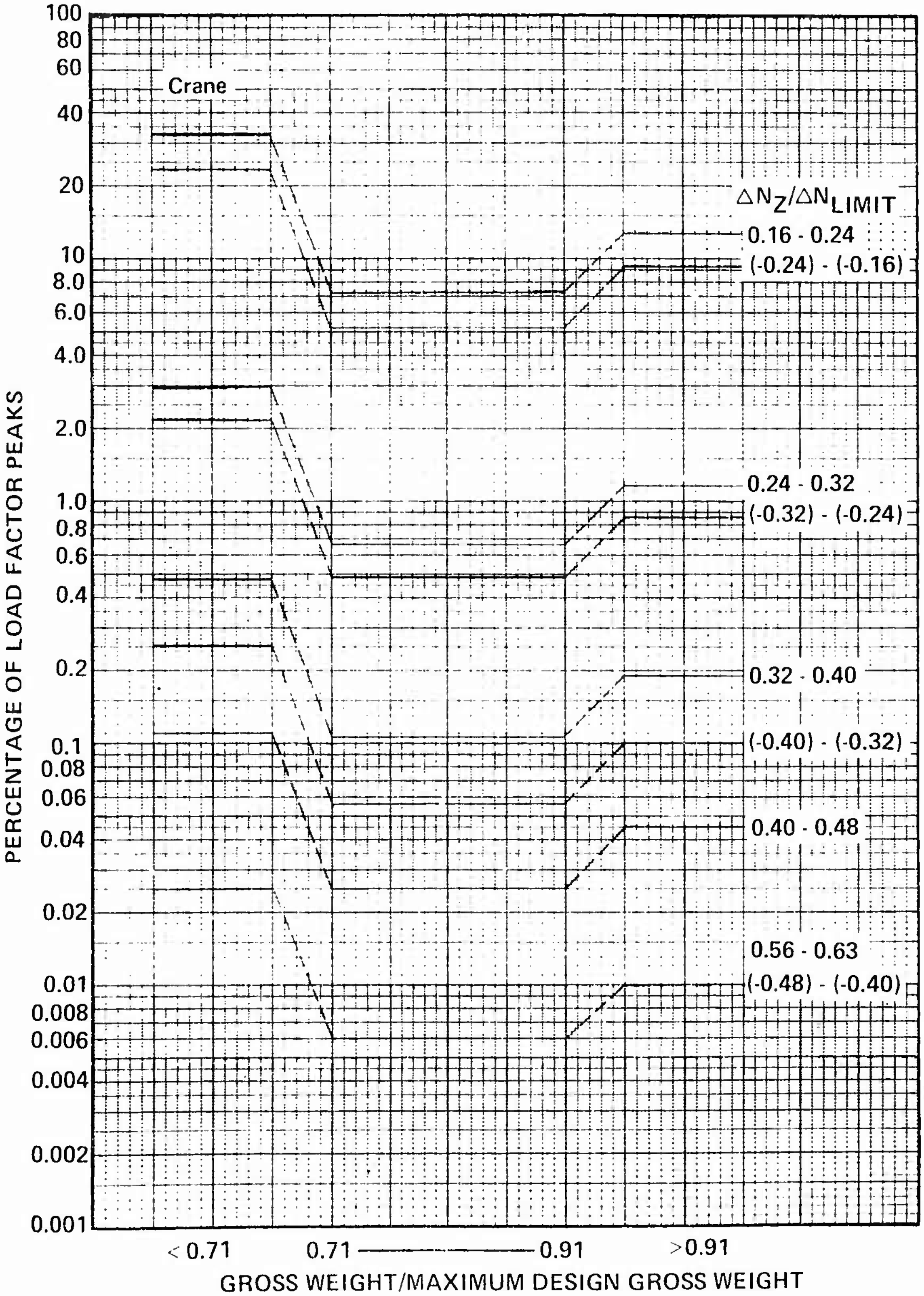


Figure 16. Load Factor-Gross Weight Distribution, Crane Type.

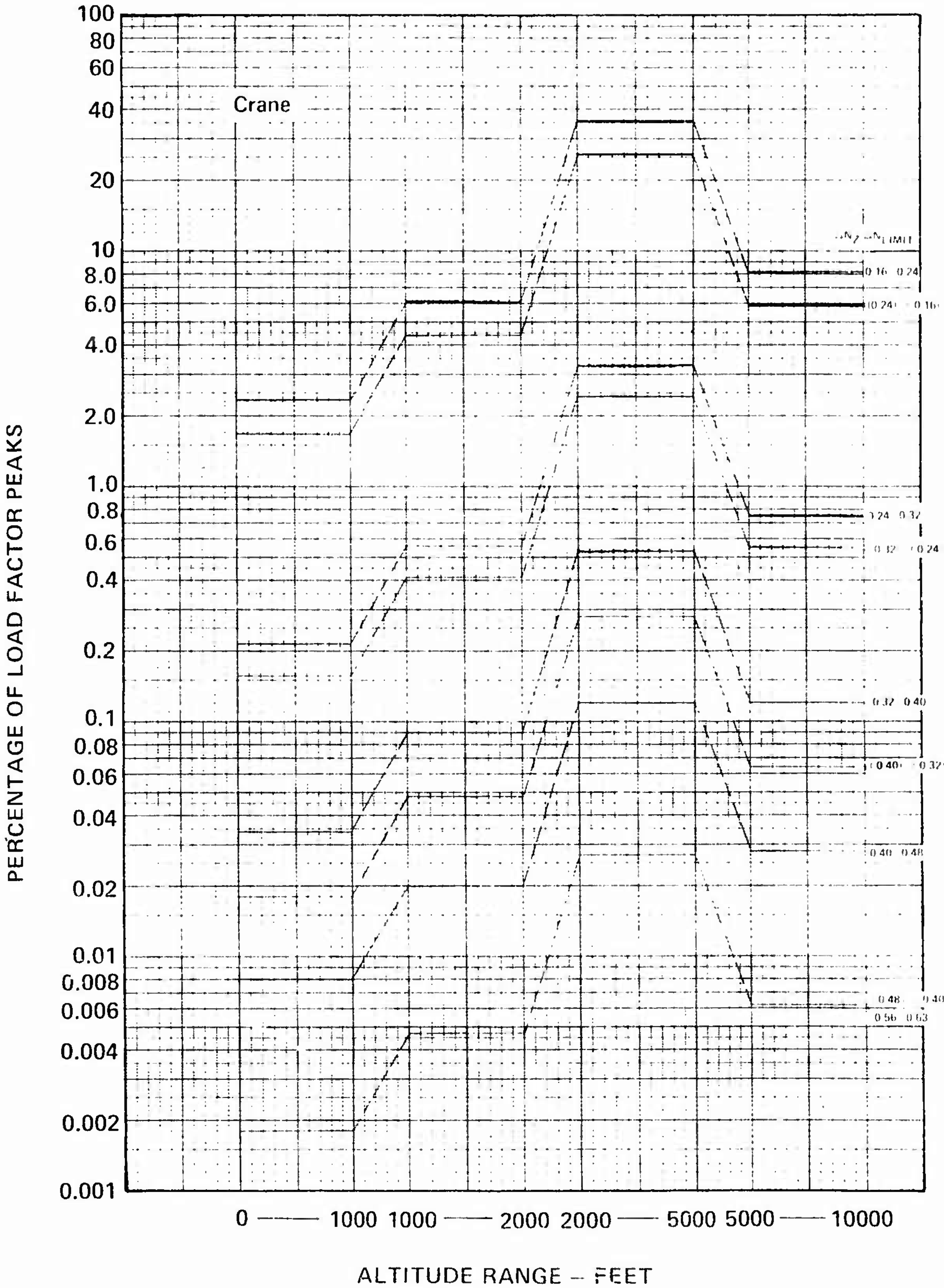


Figure 17. Load Factor-Altitude Distribution, Crane Type.

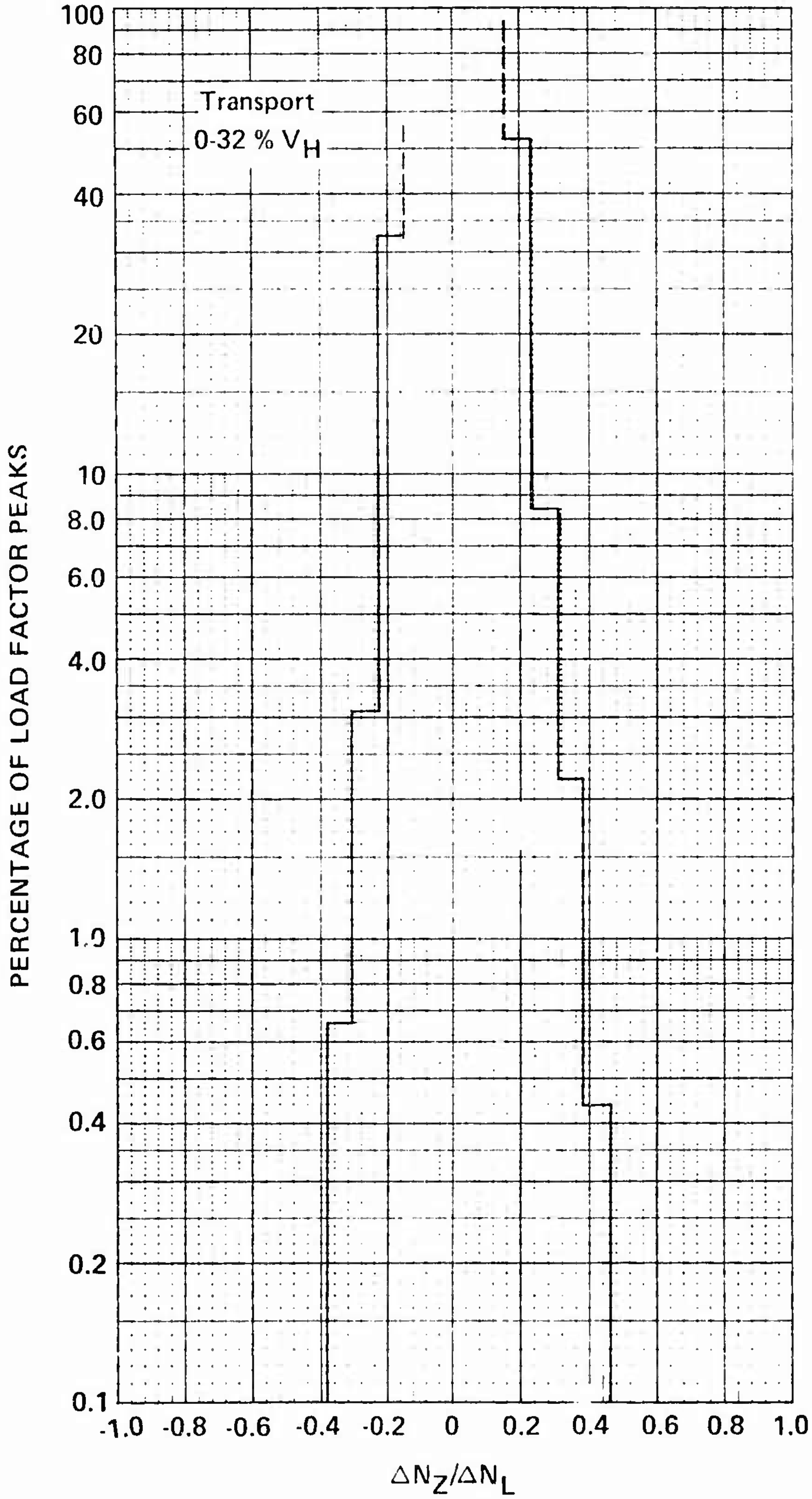


Figure 18a. Load Factor-Airspeed Distribution, Transport Type.

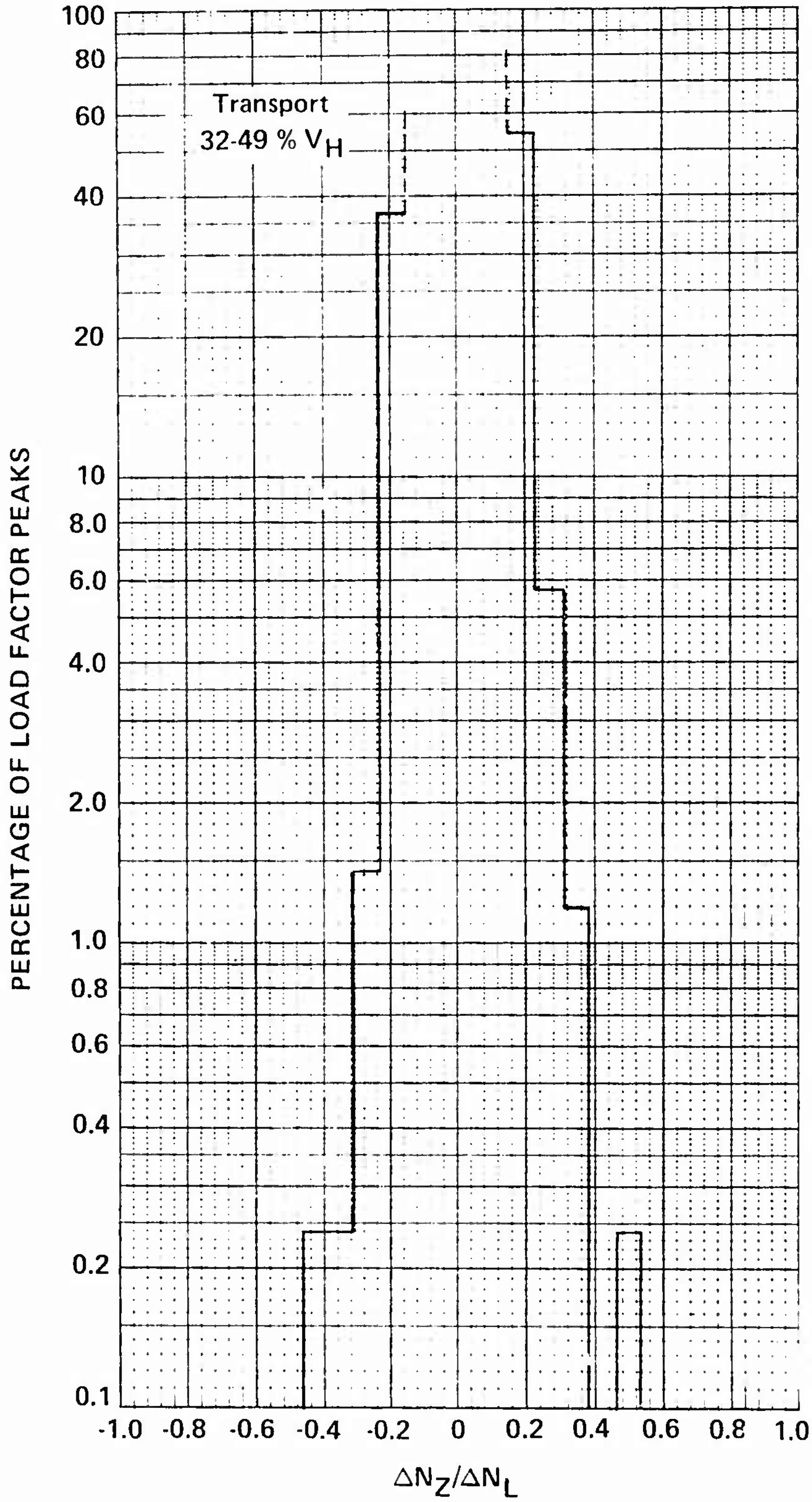


Figure 18b. Load Factor-Airspeed Distribution, Transport Type.

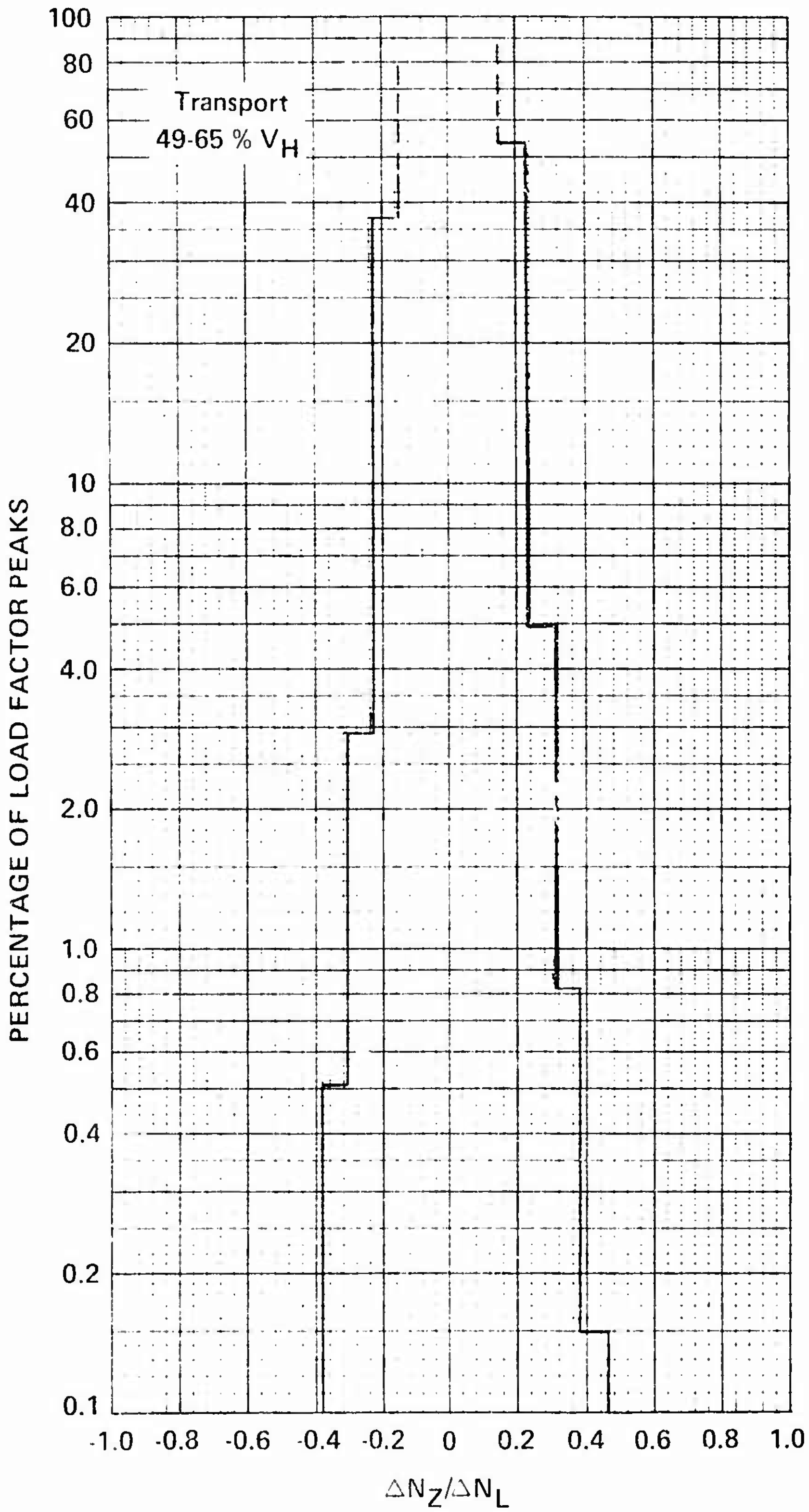


Figure 18c. Load Factor-Airspeed Distribution, Transport Type.

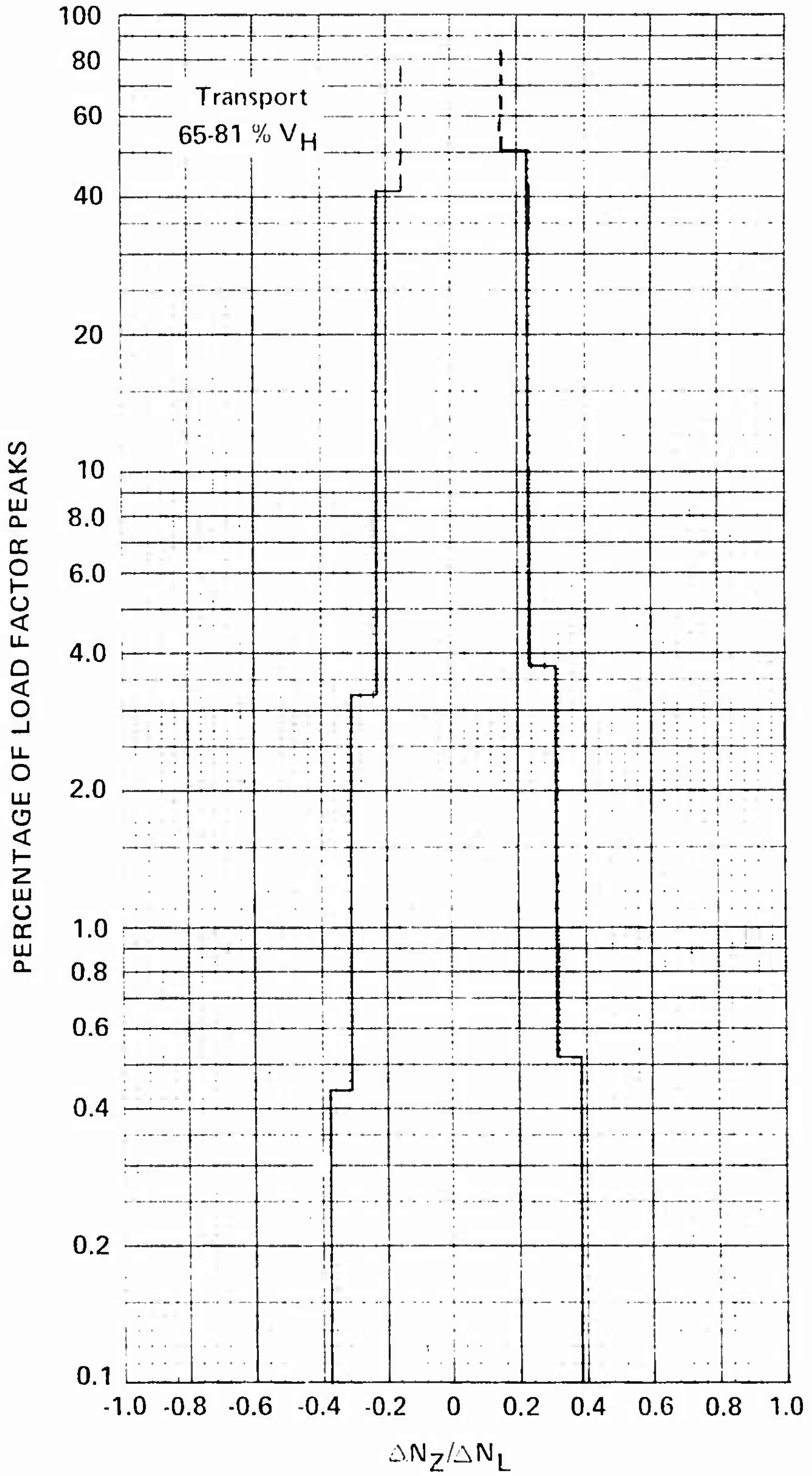


Figure 18d. Load Factor-Airspeed Distribution, Transport Type.

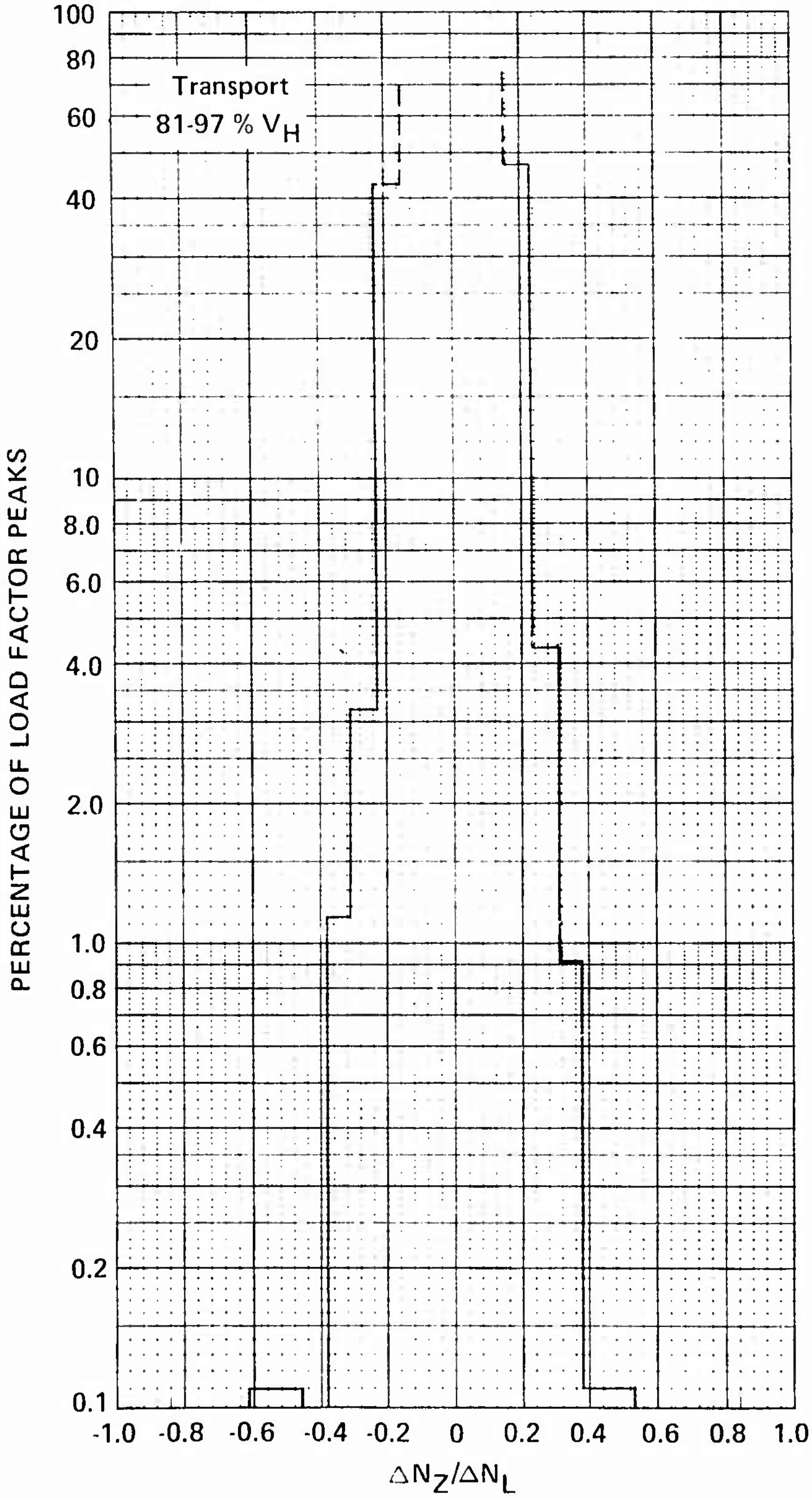


Figure 18e. Load Factor-Airspeed Distribution, Transport Type.

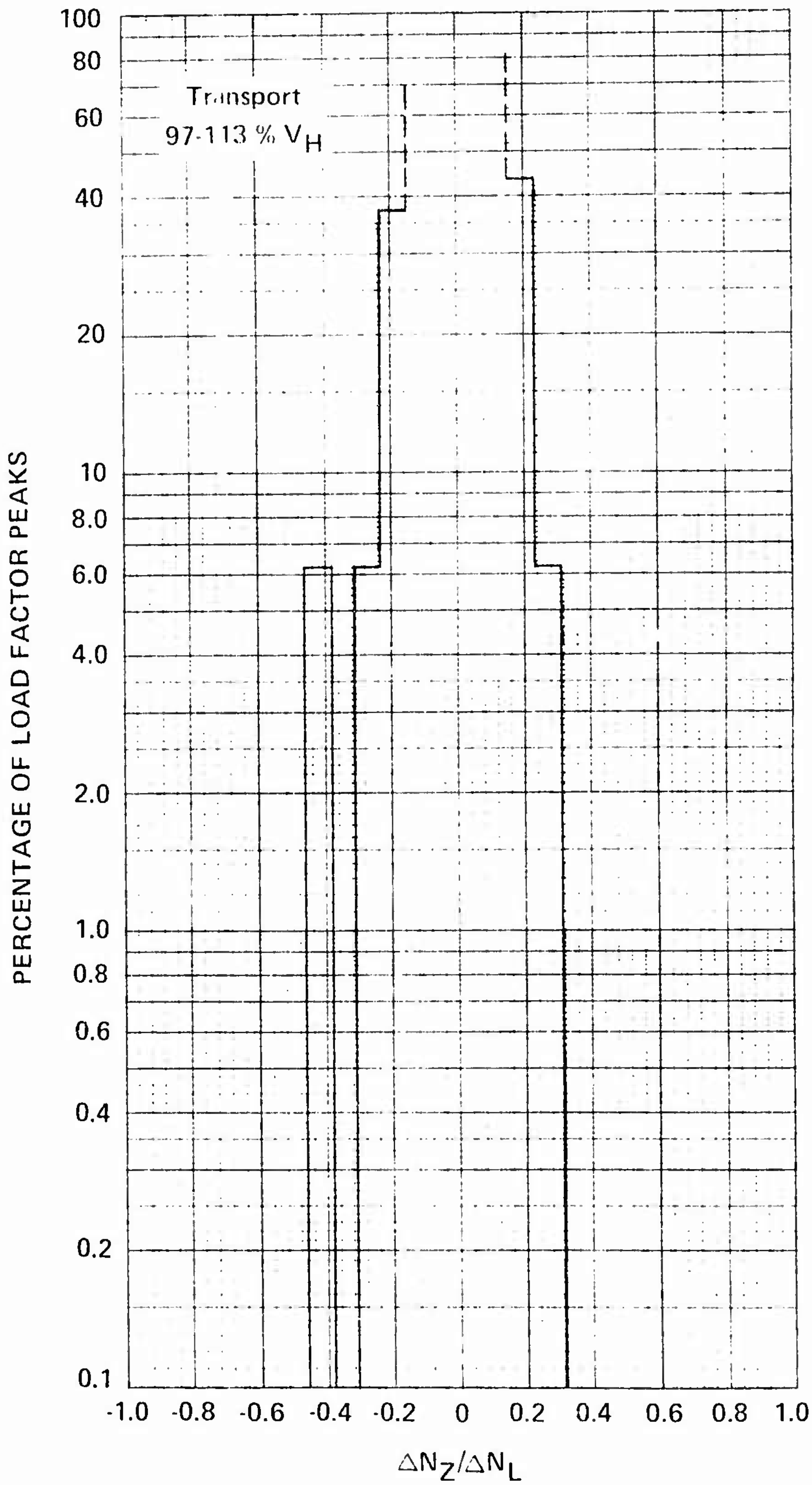


Figure 18f. Load Factor-Airspeed Distribution, Transport Type.

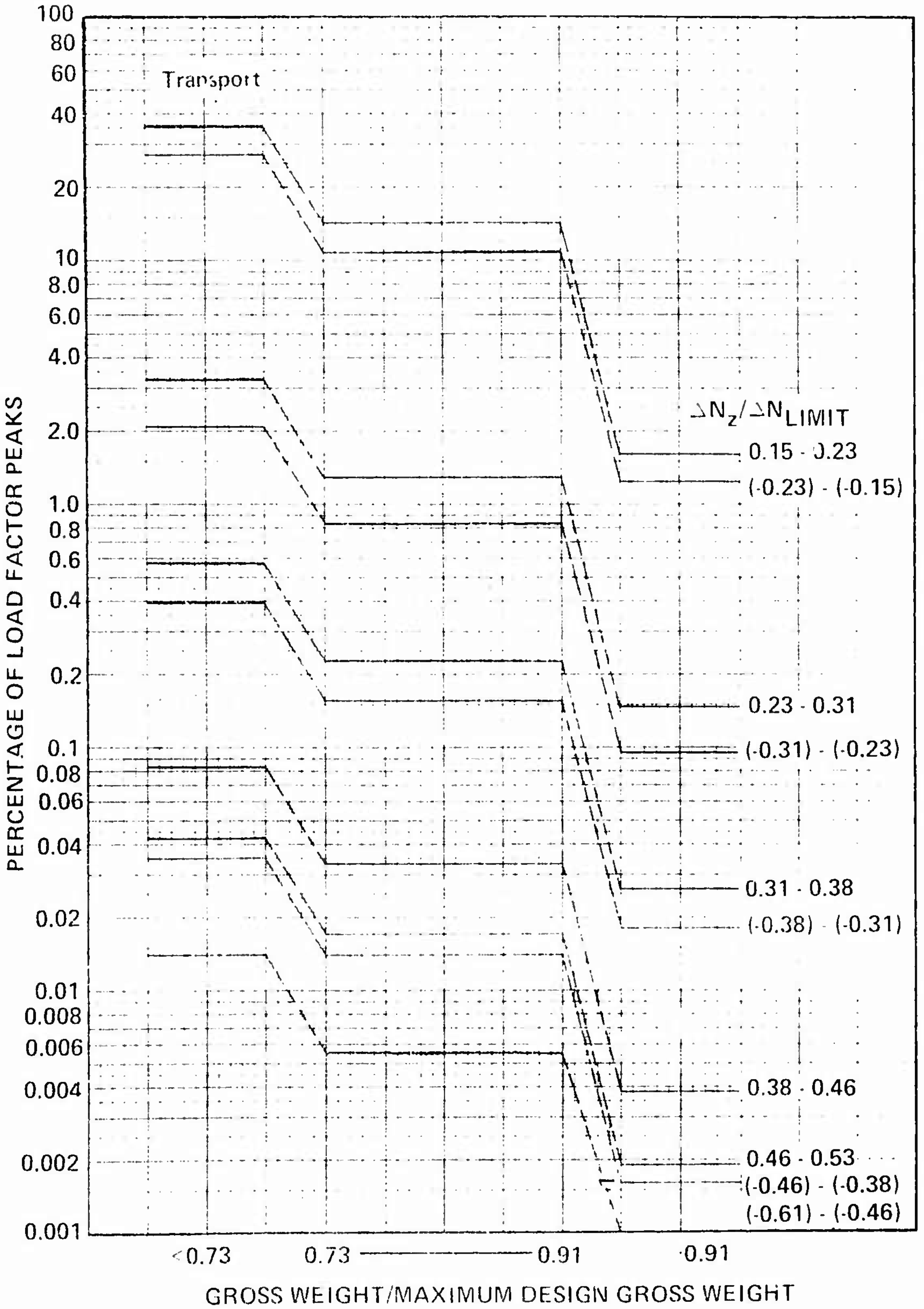


Figure 19. Load Factor-Gross Weight Distribution, Transport Type.

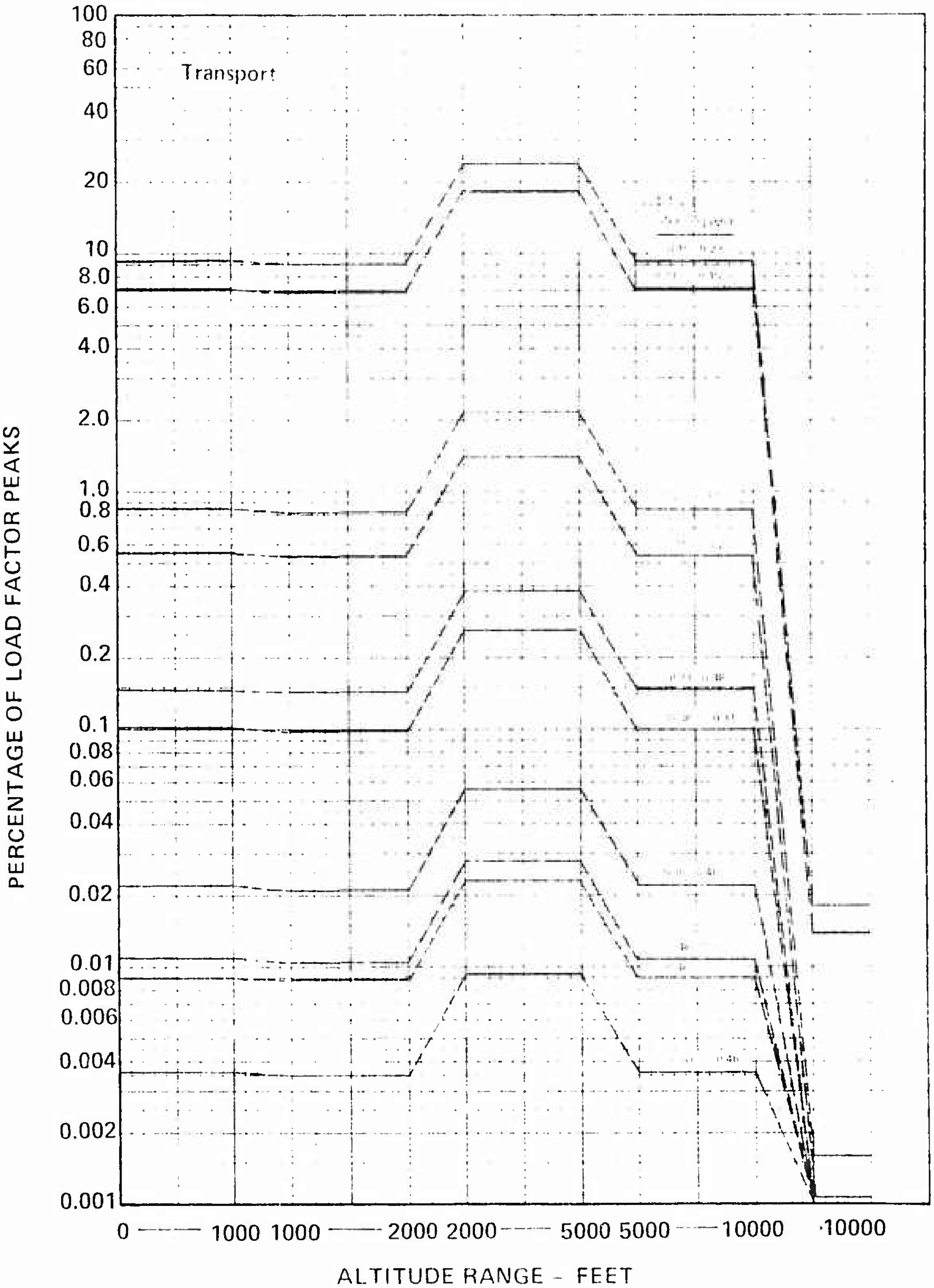


Figure 26. Load Factor-Altitude Distribution, Transport Type.

TASK III - EVALUATION OF DEVELOPED MISSION PROFILES

DIFFERENCES BETWEEN DESIGN AND OPERATIONAL DATA

Table IV presents a peak value comparison of design and operational flight loads parameters, showing the major differences between model specification and actual utilization data. The data shown were obtained from References 20 through 23 and are applicable to the observation, attack, crane, and transport helicopters. Model specification data were not available for the utility and utility/tactical assault type helicopters.

The flight loads parameters covered on the table are airspeed, vertical acceleration, engine power, rpm, and gross weight. Control positions are not included inasmuch as the design limiting characteristics exist as physical stops and not as flight manual limitations that can be exceeded. Some gaps exist on the table because the reference material does not show data for all of the flight loads parameters.

Tables V through IX list the limiting factors which influence the magnitude of the flight load parameter peak values. Each table represents a single parameter and includes the limiting factors by helicopter type. Two general limiting factors which would have a major effect on the operational peak values of all the parameters are not included on the table but are discussed in the paragraphs which follow.

The degree to which the operational data were biased by the pilots because they knew they were being monitored is unknown. An unbiased sample, if such were possible, would be of greater value. The overall effect of this factor would be to cause the operational peaks to be lower than the corresponding design peak values.

The other general limiting factor relates to the tactical procedures employed in the theater of operation associated with the data sample. This factor could cause the operational peaks to be either higher or lower than design limits as the following examples show.

High-speed dives were employed only sparingly by the attack helicopter. Table IV shows the attack helicopter operational peak airspeed to be considerably less than the maximum design value. Conversely, the crane helicopters involved in the operational data sample flew a significant number of missions at gross weights greater than the design maximum (refer to Table IV).

TABLE IV. PEAK VALUE COMPARISON - DESIGN VERSUS OPERATIONAL DATA

Parameter	Observation (Reference 23) Design	Observation (Reference 23) Operational	Attack (Reference 21) Design	Attack (Reference 21) Operational	Crane (Reference 20) Design	Crane (Reference 20) Operational	Transport (Reference 22) Design	Transport (Reference 22) Operational
Airspeed, knots	130, V_{NE} (SL)	<124 (<130)	222	185	126.5 IAS, V_D (V_H = 110 IAS)	120 EIAS 132 IAS (GW = 27,[illegible] lb)	(See Reference 22, pages 34 and 35)	
Vertical acceleration, g	2.[illegible] (2,100 lb) 2.55 (2,4[illegible] lb)	<2.2[illegible] (<2.4[illegible])	[illegible].50 (6,[illegible] lb) 2.43 ([illegible],500 lb)	2.40	2.26	1.88 (hoist) 1.5[illegible]	2.70 (28,500 lb)	1.70
	-0.5[illegible]	[illegible]0.2[illegible] ([illegible])	-0.50	0.10	-0.50	[illegible]0.50	2.35 (33,000 lb)	1.40
					1.30 (gust) [illegible]0.60 (gust)	1.[illegible] (gust)	-0.50	0.20
					(25,000 lb, 105 IAS)	(42,[illegible] lb, 110 IAS)		
Engine torque pressure, psi	80.3	<80	62.5	<60	-	-	-	-
Rpm.								
Maximum	514 (power off) 484	<4[illegible]	[illegible]56 (power off) 356	3[illegible]1	215 (power off) 204	1[illegible]8 (60 IAS) 203 (hover)	-	-
Minimum	470 40[illegible] (power off)	>440	2[illegible]4 2[illegible]4 (power off)					
Gross weight, lb	2,4[illegible]	<2,6[illegible]	[illegible],500	[illegible],522	42,000	44,[illegible]	-	-

TABLE V. LIMITING FACTORS WHICH INFLUENCE THE MAGNITUDE OF PEAK VALUES; LOAD PARAMETER: AIRSPEED
<u>OBSERVATION</u> (Reference 23) 1. Pilot visual clues (e.g., high rate of descent) 2. Retreating blade tip stall/rotor system design • Noise • Some pitch-up • Vibration 3. Structural/canopy design (at low density altitudes) <u>ATTACK</u> (Reference 21) 1. Pilot visual clues (e.g., steep dive angle, closure speed) 2. Reaction time for recovery from engine failure 3. Vibration 4. Recovery constraints <u>CRANE</u> (Reference 20) 1. Pilot visual clues (e.g., severe nose-down attitudes) <u>TRANSPORT</u> (Reference 22) 1. Cockpit vibration

Operational peak airspeeds for the crane and transport helicopters exceeded the design maximum values, whereas the airspeeds attained by the observation and attack helicopters were less than the model specification limits. This can be attributed to the stronger influence imposed on airspeed by the limiting factors for the observation and attack types as shown on Table V, and the operational environment and tactics used in the combat situation.

The vertical acceleration (load factor) data presented in Table IV shows that all four helicopter types operated within the design load factor envelopes. The limiting factors for vertical acceleration apparently exert a very strong effect.

TABLE VI. LIMITING FACTORS WHICH INFLUENCE THE MAGNITUDE OF PEAK VALUES; LOAD PARAMETER: VERTICAL ACCELERATION

OBSERVATION (Reference 23)

Minimum Load Factor

1. Pilot physical clues

Maximum Load Factor

1. Pilot physical clues
2. Retreating blade tip stall
   - Noise
   - Some pitch-up
   - Vibration
3. Bank angle in turns

ATTACK (Reference 21)

Minimum Load Factor

1. Pilot physical clues

Maximum Load Factor

1. Control feedback forces
2. Rotor system design

The engine power data are inconclusive for two reasons. The design and operational reports (References 20 and 22) for crane and transport helicopters do not address engine power, and the flight loads investigation data for the observation and attack helicopters do not present absolute maximums. This latter problem of presenting operational data in ranges instead of peak values has been criticized in earlier efforts and will not be pursued further in this report.

Rotor rpm was generally controlled within the design limits during operation. Some question was raised by the author of Reference 30 regarding the validity of the crane operational rotor speed data. Refer to Reference 20 for a detailed discussion of rotor speed comparions.

TABLE VII. LIMITING FACTORS WHICH INFLUENCE THE MAGNITUDE OF PEAK VALUES; LOAD PARAMETER: ENGINE TORQUE PRESSURE
OBSERVATION (Reference 23)
1. High collective position
2. Rpm bleedoff/engine power available
ATTACK (Reference 21)
1. Engine power available

TABLE VIII. LIMITING FACTORS WHICH INFLUENCE THE MAGNITUDE OF PEAK VALUES; LOAD PARAMETER: RPM
OBSERVATION (Reference 23)
Minimum RPM
1. High collective download (autorotation); occurs at high gross weights and airspeeds
Maximum RPM
1. Tail rotor noise/tail rotor design
2. Advancing blade tip Mach number (drag rise) in extreme cases only/rotor system design
3. Transmission noise/transmission design

TABLE IX. LIMITING FACTORS WHICH INFLUENCE THE MAGNITUDE OF PEAK VALUES; LOAD PARAMETER: GROSS WEIGHT
CRANE (Reference 20)
1. High cockpit vibration

The limiting factors which influenced gross weight were not sufficiently effective to discourage operation at gross weights greater than the design maximum for all helicopter types. The consensus from the reference material is that the pilots tended to take off at whatever gross weight could be lifted.

This effort was hindered by the lack of data shown in the design and operational studies for the four helicopter types (References 20 through 23). Tables IV through IX reflect this situation. At the time that the proposal was generated for this study, this contractor had only his design and operational study (Reference 23) in hand and assumed that the content of the other three studies would be similar. A review of those documents showed that this was not the case.

COMPARATIVE REALISM EVALUATION OF DEVELOPED PROFILES

The realism of the six mission profiles developed in Task II can be evaluated by comparing them to the profiles presented in References 1 through 3. The profiles presented in References 1 through 3 were not compatible with the developed profiles of Task II, in that the basic conditions and mission segments varied. Therefore, to allow direct comparison of percentage of occurrence values, the basic conditions of CAM-6, AR-56, and AMCP 706-203 were broken down into conditions compatible with the developed profiles, and the percentage of occurrence values were redistributed. Only four of the profiles from AR-56 (Reference 1) were directly applicable: the utility, attack, crane, and transport helicopter types. Therefore, the developed profiles for these four types of helicopters are compared to those from AR-56 in addition to the general profiles of CAM-6 and AMCP 706-203. These profiles are presented in Table X. A comparative discussion of each mission segment is presented in the following paragraphs.

1. Ground Operations. The percentage values assigned to ground operations in the developed profiles are greater than the values from References 1 and 2. The reference profiles considered ground conditions very generally, and it was difficult to establish precisely what was classified as a ground condition. When the percentage values assigned to ground conditions as shown in the referenced profiles were distributed among the conditions of the developed profile, they seemed to be too low, especially if converted to units of flight time. The values of Reference 3 seem slightly high. Hence the values assigned to ground operations for the developed profiles were felt to be the most realistic.

TABLE X. COMPARISON OF CURRENT PRACTICES IN CAM-6, AR-[illegible], AND AMC-[illegible] [illegible]

[illegible]	AMC-[illegible]		[illegible]		[illegible]		[illegible]		[illegible]	
	CAM-6	[illegible]	AR-[illegible]	[illegible]	AR-[illegible]	[illegible]	AR-[illegible]	[illegible]	AR-[illegible]	[illegible]
I. [illegible] OPERATIONS										
A. Startup	[illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	
B. Shutdown	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
C. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D. Taxi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
II. TAKEOFF, LANDING, [illegible] FLIGHT [illegible]										
A. [illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B. [illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
D. [illegible]	[illegible]	[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
E. Hover [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
F. Hover [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
G. Hover [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
H. [illegible]					[illegible]	[illegible]	[illegible]		[illegible]	
I. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
J. [illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
K. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
L. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
M. [illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
N. [illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
O. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	24.45	[illegible]
III. ASCENT [illegible]										
A. Steady-state climb	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
B. Turns	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
C. [illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

2. Takeoff, Landing, and Low-Speed Flight. The developed profiles for the four helicopter types in Table X show mission segment values which compare reasonably well with the values of References 2 and 3. However, the values from AR-56 (Reference 1) are considerably higher than those of the developed profiles, especially for the utility and attack type helicopters. At the basic condition level, the greatest differences appear in the values assigned to steady hover. Realizing that the helicopter's ability to hover is a unique feature over other types of air vehicles, the developed profiles indicate that not as much time is spent in a steady hover as indicated by previous profiles. In most helicopter operations, steady hover is a momentary flight condition occurring prior to the transition from takeoff to forward flight. The exceptions are helicopters involved in load-lifting operations (crane) and stationary weapons delivery (attack).

3. Ascent Conditions. As reflected in the percentage of occurrence values, more time was allotted to ascent conditions for the developed profiles than in the reference profiles. Based on the operational reports, it was determined that more time was spent in ascent conditions than indicated by initial design profiles. When the percentage values are converted to flight time values for a given flight period, the values for the developed profiles are more realistic than the referenced profile values.

4. Forward Flight Conditions. The percentage of occurrence values assigned to forward flight conditions compare reasonably well for all of the developed profiles and the reference design profiles. However, the developed profile values indicate slightly less time spent in the forward flight mission segment than indicated by the profiles. The greatest differences occur in the steady level flight and forward flight turns basic conditions. The developed profiles show less time spent in steady level flight and more time spent in turns. After analysis of the data in the operational reports, the percentage values for the developed profiles are considered to be more realistic.

5. Descent Conditions. The percentage of occurrence values assigned to the descent mission segment are comparable between the referenced profiles and the developed profiles, with the developed profile values being only slightly greater. The largest difference occurs for the attack helicopter, where more time is assigned to descending turns and pullups than in the referenced profiles. The larger values would appear to be more realistic

considering the attack helicopter mission, which involves greater than normal amounts of time spent maneuvering in most mission segments. Other differences between design and developed profile values are related to the missions for the helicopter types. For example, the percentage of occurrence value assigned to the crane helicopter for the dive basic condition is considerably less than the value taken from AR-56 (Reference 1). Realistically, the crane would encounter a power dive very rarely, and the time spent in this condition should reflect a very small percentage of the total flight time.

6. Autorotation. With the exception of Reference 2, the percentage of occurrence values for the autorotation mission segment for all of the profiles compare quite closely. The developed mission profiles for the utility, crane, and transport helicopters show slightly more time spent in the autorotation segment than indicated by References 1 and 3. The developed profiles indicate a greater percentage of occurrence of the steady descent basic condition than the referenced profiles. Routine pilot training procedures involve a certain amount of time in autorotation conditions. The values indicated by the referenced design profiles appear to be somewhat unconservative, and more time was assigned to autorotation conditions in the developed profiles to make the percentage of occurrence values appear more realistic.

EVALUATION OF REALISM OF LOAD FACTOR DISTRIBUTIONS

Several of the operational flight loads studies briefly discuss the importance of establishing general usage mission profiles for different helicopter types. The flight conditions encountered by a particular type of vehicle can be a direct result of the type of mission, i. e., combat versus non-combat and load lifting versus utility. As determined from some of the operational flight loads studies, the mission profiles for certain helicopter types were not typical of what could be called intended usage profiles. In the absence of a clear definition of an intended usage mission profile for each helicopter type, some basic assumptions were made regarding whether or not certain flight conditions would normally be encountered during an intended usage mission profile. These assumptions will become apparent in the following discussion of the realism of the load factor distributions for helicopter type.

Observation

In the case of the observation helicopters, the distributions are based primarily on data obtained from studies conducted in a combat environment.

The study vehicles were equipped with armament and, as a result, probably encountered flight conditions that could be labeled gunnery maneuvers. Conditions that might be more typical of an attack or utility/tactical assault type of helicopter may have been performed. This is evidenced by the higher percentage of mission time spent in the maneuver segment as opposed to the other segments presented in Reference 17. However, evasive maneuvers to avoid ground fire while serving in a purely observation capacity would be considered a part of an intended usage mission profile.

An observation helicopter performing attack or support mission functions would most likely encounter those flight conditions which have a significant effect on load factor and airspeed distributions. Also, gross weight distributions would be affected because of increased loading due to armament and, in some cases, additional personnel to operate the armament. For these reasons, the operational load factor data for the observation helicopter seemed to indicate a more severe load factor environment than might normally be encountered for an observation helicopter. However, in a combat situation, this severe load factor environment could be considered to be realistic since close-in observation and rapid maneuvering to avoid ground fire could produce a severe load factor distribution.

Utility

For the utility helicopter, the percentage distribution of load factor peaks with airspeed is relatively constant across the airspeed spectrum. This would be the expected trend for a utility helicopter because of the type of mission normally flown: resupply, cargo, and personnel transport. The subject vehicles of Reference 18 that were classified as utility helicopters fell into both assault and nonassault roles. As a consequence, the load factor distributions were influenced by flight conditions encountered during the assault role that might not have occurred during a purely utility mission.

The load factor-gross weight distribution shows that the mid and high gross weight ranges contain the greatest percentages of load factor peaks. This might be considered a realistic trend considering that the utility helicopter is intended to function in a load-carrying capacity.

The load factor peaks encountered at a particular density altitude would be a function of the operational environment. Disregarding the density altitude requirements for this type of helicopter, the vehicle would normally be expected to operate at altitudes above ground level of 0 to 5000 feet. The load factor-altitude distribution indicates that the greatest number of load factor peaks occurred in the mid-altitude range (2000 to 5000 feet).

Utility/Tactical Assault

The flight loads studies which covered helicopters that could be labeled as utility/tactical assault vehicles were conducted in a simulated combat environment (Reference 11). The missions included air assault exercises as well as routine training and field maneuvers. The results of these studies indicated that the distribution of load factor with airspeed remained relatively constant throughout the airspeed spectrum. This would seem conservative for a vehicle in an actual combat mission involving personnel transport and ground fire support of ground personnel. During these missions it would be expected that the vehicle would spend more time in load-factor-producing conditions than the pure utility or observation helicopter.

The greatest percentage of load factor peaks occur in the mid and high gross weight ranges. This would be an expected trend for a utility/tactical assault helicopter that spent most of the time in assault troop transport or tactical fire support missions. From an operational standpoint, mission weight is important in determining vehicle efficiency. Partially loaded or unloaded vehicles are not as efficient in an operational sense as fully loaded vehicles.

The load factor-altitude distribution indicates that the utility/tactical assault helicopter encounters increasingly greater percentages of load factor peaks as the altitude increases. Above the 5000-foot level, the percentage of peak values drops off considerably. Again, this would be the expected trend for a vehicle that, by mission requirement, might spend most of the time in low-altitude tactical support missions.

Attack

The attack helicopter role dictates certain design requirements in order to fulfill the intended mission. One of the most significant of these is high maneuverability. The load factor distributions for the attack helicopter are significantly greater in both range and magnitude than those for the other types. The higher load factor peaks occur at the higher airspeeds. These would be expected trends for an attack helicopter involved in search and destroy or ground assault mission profiles. These missions normally could include large segments of flight time spent in weapons delivery maneuvers indicative of a hostile combat environment and which would involve more than normal amounts of time in maneuvering flight conditions. For these reasons, the load factor distribution for an attack helicopter would be expanded in magnitude over those of other types of helicopters.

Mission efficiency for this type of helicopter directly relates to the weapons carried and, therefore, might be expected to operate at the higher gross weights during most of its flight time. This is indicated by the operational report of Reference 16, which shows greater amounts of time spent at mid to high gross weights. Because of this, the load factor-gross weight distribution shows a greater percentage of load factor peaks occurring at the higher gross weights.

The load factor-altitude distribution shows that the highest percentage of load factor peaks occurred in the 2000- to 5000-foot altitude range. These values are strongly influenced by the type of mission for which an attack helicopter is designed. The intended mission would involve search at altitude for enemy positions and attack at a lower altitude to destroy those positions. Maneuvers encountered during the attack phase of the mission would possibly account for the majority of the load factor peaks during a given mission.

Crane

As mentioned previously in Task II, the load factor-airspeed distribution for the crane helicopter encompasses a narrow range of load factor peaks. This is a direct result of the crane's intended mission, specifically, cargo transport, hoist operations, and oversized external sling loads. In an external load configuration, a crane helicopter would normally avoid high-load-factor-producing flight conditions. Also, high maneuverability is not a prime design criterion for a crane helicopter. The fact that the percentages of low load factor peaks are significantly higher than those for other helicopter types points out that crane helicopters avoid high-load-factor-producing flight conditions.

The load factor-gross weight distribution for the crane helicopter indicates that the lowest percentage of load factor peaks occur in the mid gross weight range. This would be the expected trend for a helicopter that was designed to carry heavy external loads but which, in an unloaded configuration, has a gross weight significantly less than the maximum design gross weight. The greatest percentages of load factor peaks would occur at either low or high gross weights.

In a load transporting configuration, a crane helicopter would not normally be expected to fly at high altitudes. Also, if the vehicle was performing the intended mission, this type would spend a large portion of the total time at an intermediate altitude in transit from one point to another. This can be seen in the load factor-altitude distribution, where the greatest percentage of load factor peaks occur in the 2000- to 5000-foot altitude range.

Transport

The intended mission profile for a transport helicopter normally would include the transport of personnel and/or equipment from one location to another. In this respect, the mission is very much the same as that for the crane helicopter. This is also indicated by the load factor-airspeed distribution for the transport, which, like the crane, has relatively narrow bands of load factor peaks ($\Delta N_Z/\Delta N_L$) and a relatively even percentage distribution of peaks across the airspeed spectrum.

The load factor-gross weight distribution for the transport helicopter indicates that the greatest percentage of load factor peaks occur in the low gross weight range. Although there is no indication of why this is the case in the referenced material, this might be due to the avoidance of high-load-factor-producing flight conditions while at the heavier gross weight configurations.

As for the crane, the transport helicopter incurs the greatest percentage of load factor peaks in the mid-altitude range of 2000 to 5000 feet. Because of the similarity in the missions between the crane and transport, the same trends in the load factor distributions would be expected.

TASK IV - IDENTIFICATION OF CRITICAL SEGMENTS/CONDITIONS

The objective of this task is to identify the mission profile segments and basic conditions which have high structural loads, high fatigue damage, and/or high vibration. Structural loads and fatigue damage are associated with specific components, while vibration is not related to a specific component but is a general indicator of high loads. Therefore, these subjects are discussed separately below.

HIGH STRUCTURAL LOADS AND FATIGUE DAMAGE

The distinction between high structural loads and high fatigue damage is very important in this study. Variation in the percentage of occurrence for basic conditions which produce high loads or high fatigue damage can cause large changes in the fatigue life of a component. This is especially true of conditions which produce high loads. There are many conditions which produce high loads but, because they occur so rarely, do not cause high fatigue damage. Small increases in the percentage of occurrence of these conditions can significantly affect the life of that component. Conditions in these categories have been identified by analyzing the load and fatigue data supplied in the design and operational reports (References 20 through 23). The scope of this effort is limited by the number of components for which data were given. Each basic condition generally affects one group of components more severely than others; consequently, basic conditions which affect components not surveyed cannot be identified. Tables XI through XIV identify critical conditions for the components available. Conditions are identified if any of the parameters (gross weight, load factor, airspeed, etc.) produce any of the critical conditions marked. Table XI is OH-6A data (Reference 23) representing an observation helicopter. Table XII presents AH-1G data (Reference 21) for the attack helicopter. The crane helicopter is represented by CH-54A data (Reference 20) given in Table XIII. CH-47A data (Reference 22) is given in Table XIV, representing a transport helicopter. Because References 24 through 30 were not available, the utility and utility/tactical assault helicopters are discussed separately. For purposes of this analysis, a condition which produced a load at least 50 percent greater than the endurance limit or contributed more than 2 percent of the total fatigue damage of a component was identified as having high load or high fatigue damage respectively. In addition the tables include a column entitled "Causal Factor"; the numbers in this column refer to Table XV and are discussed later in this task.

TABLE XI. CRITICAL CONDITIONS - OBSERVATION (OH-6A)

Condition	High Vibration	Main Rotor Blade Flap Bend at 15 Percent Span: High Load	High Fatigue Damage	Causal Factor
<u>GROUND OPERATIONS</u>				
Startup				
Shutdown				
Ground run				
Taxi				
<u>TAKEOFF/LANDING/LOW SPEED</u>				
Vertical lift-off and acceleration			X	4
Rolling takeoff				
Slide-on landing	X			
Hover (steady)				
Hover control reversals				
Hover turns				
Pop-ups				
Sideward flight				
Rearward flight				4
Low-speed forward flight				4
Flare	X		X	4
Vertical climb				
Vertical descent		X	X	4
Low-speed turns				
<u>ASCENT</u>				
Steady climb				
Turns				
Pushovers				
<u>FORWARD FLIGHT</u>				
Level flight				
Turns		X	X	1, 3
Control reversals		X	X	1, 3
Pull-ups	X	X		3
Pushovers				
Deceleration				
Acceleration				
Yawed flight				
<u>DESCENT</u>				
Partial power				
Dive		X		2
Turns		X	X	2, 3
Pull-ups	X	X		2, 3
<u>AUTOROTATION</u>				
Entries				
Steady descent				
Turns		X		2, 3
Power recovery				
Flare and landing			X	4

		Main Rotor Blade		Main Rotor Grip		Main Rotor Yoke Extension		Swashplate Outer Ring		Tail Rotor Blade		Tail Rotor Grip		
Condition	High Vibration	High Load	High Fatigue Damage	High Load	High Fatigue Damage	High Load	High Fatigue Damage	High Load	High Fatigue Damage	High Load	High Fatigue Damage	High Load	High Fatigue Damage	Causal Factor
FORWARD FLIGHT														
Level flight														
Turns	X	X	X		X		X		X	X	X			[illegible]
Control reversals														
Pull-ups	X	X												
Pushovers														
Deceleration														
Acceleration	X													
Yawed flight	X													
DESCENT														
Partial power														
Dive	X	X	X								X			[illegible]
Turns														
Pull-ups	X	X	X				X		X	X	X		X	[illegible]
AUTOROTATION														
Entries														
Steady descent														
Turns														
Power recovery														
Flare and landing		X					X							[illegible]

TABLE XIII. CRITICAL CONDITIONS - CRANE (CH-54A)

Condition	High Vibration	Main Rotor Shaft: High Load	Main Rotor Shaft: High Fatigue Damage	Main Rotor Hub: High Load	Main Rotor Hub: High Fatigue Damage	Magnetic Main Rotor Spacer: High Load	Magnetic Main Rotor Spacer: High Fatigue Damage	Aluminum Main Rotor Spacer: High Load	Aluminum Main Rotor Spacer: High Fatigue Damage	Causal Factor
GROUND OPERATIONS										
Startup										
Shutdown										
Ground run										
Taxi										
TAKEOFF / LANDING / LOW SPEED										
Vertical lift-off and acceleration										
Rolling takeoff										
Slide-on landing										
Hover (steady)			X		X		X		X	[illegible]
Hover control reversals										
Hover turns			X		X		X		X	[illegible]
Pop-ups										
Sideward flight			X		X		X		X	4, [illegible]
Rearward flight			X		X		X		X	4, 6
Low-speed forward flight										
Flare										
Vertical climb										
Vertical descent										
Low-speed turns										
ASCENT										
Steady climb										
Turns										
Pushovers										
FORWARD FLIGHT										
Level flight										
Turns										
Control reversals	X	X	X	X	X	X	X	X	X	1, [illegible]
Pull-ups										
Pushovers										
Deceleration										
Acceleration										
Yawed flight										
DESCENT										
Partial power			X		X		X		X	
Dive			X		X		X		X	1, 2
Turns			X		X		X		X	1, 2, 3
Pull-ups			X		X		X		X	1, 2, 3
AUTOROTATION										
Entries										
Steady descent										
Turns										
Power recovery										
Flare and landing										

TABLE XIV. CRITICAL CONDITIONS - TRANSPORT (CH-47A)						
		Aft Plate Spar		Aft Pivoting Actuator		
Condition	High Vibration	High Load	High Fatigue Damage	High Load	High Fatigue Damage	Causal Factor
GROUND OPERATIONS						
Startup						
Shutdown						
Ground run						
Taxi						
TAKEOFF/LANDING/LOW SPEED						
Vertical lift-off and acceleration	X		X		X	4
Rolling takeoff						
Slide-on landing						
Hover (steady)						
Hover control reversals						
Hover turns						
Pop-ups						
Sideward flight	X					
Rearward flight	X					
Low-speed forward flight	X		X		X	4
Flare	X		X		X	4
Vertical climb						
Vertical descent						
Low-speed turns	X					
ASCENT						
Steady climb						
Turns	X					
Pushovers	X					
FORWARD FLIGHT						
Level flight	X					1, 2
Turns	X				X	
Control reversals	X		X			1, 2, 3
Pull-ups	X		X			1, 2, 3
Pushovers	X					
Deceleration						
Acceleration	X					
Yawed flight						
DESCENT						
Partial power						
Dive	X		X		X	2
Turns	X					
Pull-ups	X		X			2, 3
AUTOROTATION						
Entries						
Steady descent						
Turns						
Power recovery						
Flare and landing	X		X			4

HIGH VIBRATION

Since high vibration is not necessarily associated with the loads in any particular component, the occurrence of high vibration is shown independent of the components in Tables XI through XIV. For the same reason the four manufacturers who produced References 20 through 23 did not associate vibration with loads. Consequently, data on vibration were brief or nonexistent. Data which could be related to specific basic conditions are shown in Tables XI through XIV. These data have been supplemented by surveying the Hughes engineering test staff relative to their experience with vibration in articulated and tandem rotor helicopters of many different models.

CAUSAL FACTORS

High structural loads, fatigue damage, and vibration are commonly associated with the same causal factors. The cause of fatigue damage differs somewhat from the other two in that it usually occurs due to a combination of moderate to high loads and high percentage of occurrence. Conditions which are identified as producing high fatigue damage and have loads only slightly above the endurance limit are a result of a high percentage of occurrence associated with that condition. Consequently, the causal factors for fatigue damage conditions are not as severe as those associated with high loads and vibration. Table XV lists the causal factors for each condition identified in Tables XI through XIV. Each causal factor is numbered corresponding to the numbers in the causal factor column in the tables.

TABLE XV. HIGH LOADS AND/OR HIGH VIBRATION CAUSAL FACTORS
1. High cyclic blade angle
2. Advancing blade tip compressibility effects
3. Retreating blade tip stall
4. Unsteady air flow
5. High tail rotor thrust demand
6. High main rotor thrust

CRITICAL CONDITIONS FOR THE UTILITY AND UTILITY/TACTICAL ASSAULT HELICOPTER

For the helicopter types for which critical conditions have been discussed up to now, flight loads data were available in the manufacturers' reports (References 20 through 23). For the utility and utility/tactical assault helicopters, flight loads data is contained in References 24 through 30. These reports have been unavailable, though efforts were initiated early in this program to obtain them. In order to identify probable critical conditions for these types, a summary of Tables XI through XIV was made. All basic conditions were tabulated which had at least one critical condition identified for any of the four types covered in Tables XI through XIV. The components were separated into two categories: main rotor and tail rotor. This is shown in Table XVI. The summary indicates the conditions that are most likely to be critical for the utility and utility/tactical assault helicopters. Tables XVII and XVIII show conditions deduced from the summary that may be critical for the utility and utility/tactical assault helicopter, respectively.

RELATIONSHIP OF CRITICAL CONDITIONS TO MISSION PROFILES

The objective of the following discussion is to ascertain the critical conditions that are unique to a single helicopter type and those that are universally critical. The components for which loads data were available are generally not comparable to one another on an individual basis, but have been separated into main rotor components and tail rotor components. The critical condition summary, Table XVI, shows the basic conditions that are critical for each type for which data were available. In this table, a condition was identified if any one of high loads, high fatigue damage, or high vibration occurred. The simultaneous occurrence of high vibration with either of the other two is of particular importance as a pilot cue that structural damage may occur. The consistency of this relationship will also be explored.

There are several conditions that are uniquely critical to each type helicopter. Basic conditions that are critical for one or two helicopter types are shown in Table XIX as uniquely critical conditions. The reasons for these uniquely critical conditions for each type will now be reviewed.

In the case of the observation helicopter (OH-6A) the critical conditions are not related to the mission assignment. All the uniquely critical conditions are related to one of two causal factors. These are the unsteady airflow associated with transition and vertical descent, and retreating blade tip stall associated with high speed and high rotor thrust.

TABLE XVI. CRITICAL CONDITION SUMMARY

Critical Conditions	For Helicopter Type: Main Rotor	For Helicopter Type: Tail Rotor
2. TAKEOFF/LANDING/LOW-SPEED FLIGHT		
A. Vertical lift-off and acceleration	OT	
E. Hover (steady)	C	
G. Hover turns		
I. Sideward flight	OC	
J. Rearward flight	OC	A
K. Low-speed forward flight	OT	
L. Flare	OAT	
O. Vertical descent	O	
4. FORWARD FLIGHT		
A. Level flight	T	
B. Turns	OA	A
C. Control reversals	OCT	
D. Pull-ups	OAT	
5. DESCENT		
A. Partial power descent	C	
B. Dive	OACT	A
C. Turns	OC	
E. Pull-ups	OACT	A
6. AUTOROTATION		
C. Turns	O	
H. Flare and landing	OAT	

O = Observation
A = Attack
C = Crane
T = Transport

TABLE XXII. CRITICAL CONDITIONS - UTILITY UH-1B

Condition	High Vibration	Main Rotor	Design Factor
GROUND OPERATIONS			
Startup	X		
Shutdown	X		
Ground run			
Taxi			
TAKEOFF/LANDING/LOW SPEED			
Vertical lift-off and acceleration		X	4
Rolling takeoff			
Slide-on landing			
Hover (steady)			
Hover control reversals	X		
Hover turns			
Pop-ups			
Sideward flight	X	X	4
Rearward flight	X	X	4
Low-speed forward flight		X	4
Flare		X	4
Vertical climb			
Vertical descent			
Low-speed turns			
ASCENT			
Steady climb			
Turns			
Pushovers	X		
FORWARD FLIGHT			
Level flight	X	X	2
Turns			
Control reversals	X	X	1
Pull-ups	X	X	[illegible]
Pushovers			
Deceleration			
Acceleration			
Yawed flight			
DESCENT			
Partial power			
Dive	X	X	2
Turns			
Pull-ups	X	X	3
AUTOROTATION			
Entries			
Steady descent			
Turns			
Power recovery	X		
Flare and landing		X	4

TABLE XVIII. CRITICAL CONDITIONS - UTILITY/TACTICAL ASSAULT (UH-1H)				
Condition	High Vibration	Main Rotor	Tail Rotor	Causal Factor
GROUND OPERATIONS				
Startup	X			
Shutdown	X			
Ground run				
Taxi				
TAKEOFF/LANDING/LOW SPEED				
Vertical lift-off and acceleration		X		4
Rolling takeoff				
Slide-on landing				
Hover (steady)				
Hover control reversals	X			
Hover turns				
Pop-ups				
Sideward flight		X		4
Rearward flight	X	X	X	4, 5
Low-speed forward flight		X		4
Flare	X	X		4
Vertical climb				
Vertical descent				
Low-speed turns				
ASCENT				
Steady climb				
Turns				
Pushovers				
FORWARD FLIGHT				
Level flight	X			
Turns		X	X	3, 5
Control reversals		X		1
Pull-ups	X	X	X	3
Pushovers				
Deceleration				
Acceleration				
Yawed flight				
DESCENT				
Partial power				
Dive		X	X	2
Turns		X		1
Pull-ups	X	X	X	3
AUTOROTATION				
Entries				
Steady descent				
Turns				
Power recovery				
Flare and landing	X			4

TABLE XIX. UNIQUELY/UNIVERSALLY CRITICAL CONDITIONS

OBSERVATION

2. TAKEOFF/LANDING/LOW-SPEED FLIGHT
   - A. Vertical lift-off and acceleration
   - I. Sideward flight
   - J. Rearward flight
   - K. Low-speed forward flight
   - O. Vertical descent

4. FORWARD FLIGHT
   - B. Turns

5. DESCENT
   - C. Turns

6. AUTOROTATION
   - C. Turns

ATTACK

2. TAKEOFF/LANDING/LOW-SPEED FLIGHT
   - J. Rearward flight (tail rotor)

4. FORWARD FLIGHT
   - B. Turns

CRANE

2. TAKEOFF/LANDING/LOW-SPEED FLIGHT
   - E. Hover
   - I. Sideward flight
   - J. Rearward flight

5. DESCENT
   - A. Partial power descent
   - C. Turns

TRANSPORT

2. TAKEOFF/LANDING/LOW-SPEED FLIGHT
   - A. Vertical lift-off and acceleration
   - K. Low-speed forward flight

4. FORWARD FLIGHT
   - A. Level flight

UNIVERSALLY CRITICAL CONDITIONS

2. TAKEOFF/LANDING/LOW-SPEED FLIGHT
   - L. Flare

4. FORWARD FLIGHT
   - C. Control reversal
   - D. Pull-ups

5. DESCENT
   - B. Dive
   - E. Pull-up

6. AUTOROTATION
   - H. Flare and landing

Conditions critical for the attack helicopter (AH-1G) are rearward flight and turns in level flight. The rearward flight condition is not unique in that both the observation and the crane helicopters have a critical condition occurring during rearward flight; however, the attack helicopter was the only type for which the tail rotor was involved. The fact that this condition is critical is not surprising; however, the lack of the presence of high loads in the tail rotors of the other types is odd. The tail rotor of any helicopter in rearward flight must overcome negative static directional stability in addition to supplying high thrust to compensate for the high main rotor torque at very low airspeeds. It is probable that the tail rotors of the other types were designed to higher endurance limits to satisfy requirements of other conditions or ballistic invulnerability. The fact that forward flight turns are critical is directly related to the attack mission because of the high occurrence of the turn condition and the concentration of that time at higher load factors.

The crane helicopter (CH-54A) has three uniquely critical conditions, one of which is hover. Table XIII shows that hover is identified as not having high loads in any components but that high fatigue damage occurs in several components. This indicates that hover is uniquely critical to the crane helicopter because of the high percentage of hover time. It should be noted that the crane helicopter is the only type for which Causal Factor 6 is applicable due to very high gross weight operation. The design and operational report (Reference 20) indicates that high gross weight is a compounding factor causing high fatigue damage in sideward flight. There is also a high occurrence of these conditions because hovering in crosswinds and tailwinds is frequently necessary for the crane helicopter.

The transport helicopter is uniquely critical for both vertical takeoff and acceleration, and for low-speed forward flight. Both of these conditions produce high fatigue damage. High loads are likely to occur during these conditions as well, because the percentage of occurrence for the vertical lift-off and acceleration condition is not very large. However, this cannot be verified because flight loads data were not included in the design and operational report (Reference 22). The level flight condition is also identified as uniquely critical to the transport. This is due to high vibration levels at high airspeed, probably due to advancing blade tip compressibility effects. There is no relationship between the uniquely critical conditions and the transport mission.

Table XIX also lists the conditions that are critical for three or more helicopter types as universally critical conditions. These consist of six basic conditions, containing four distinct maneuvers. Each maneuver corresponds to one of the first four causal factors listed in Table XV. These four factors have been primary considerations in the design of virtually every rotorcraft.

CORRELATION OF HIGH VIBRATION WITH HIGH LOADS OR HIGH FATIGUE DAMAGE

Tables XI through XIV, XVII, and XVIII were examined to determine the consistency of high vibration occurring simultaneously with high load or high fatigue damage. None of the helicopter types showed a consistent correlation. Out of 77 conditions which had either high vibration, fatigue damage, or high loads, only 28 had a simultaneous occurrence of high vibration with either of the other events. There were 22 conditions for which high vibration occurred without high loads or high fatigue damage. The remaining 27 conditions were occurrences of high loads or high fatigue damage without high vibrations. These data indicate that while high vibration can have serious implications in its own right, high vibration may not be used to indicate the occurrence or nonoccurrence of high loads or high fatigue damage rates. Further study is recommended in this area because, while there were many instances of high vibration occurring without high loads or fatigue damage in the components shown, there may have been damage in components for which data are not available.

CONCLUSIONS

In Task I, 38 reports applicable to the dynamic loads and structural criteria study were identified, indicating active interest for over two decades in the effects of actual operational usage on helicopter fatigue life. These reports contain operational data, Government specifications, design criteria, and flight loads data. Seven of the reports could not be obtained over the short span of this contract, which limited the scope and accuracy of data presented for the utility and utility/tactical assault helicopters.

A standard format for mission profile presentation was developed in Task II in order to define uniform design requirements for various helicopter types. This format includes six distinct mission segments and a standard list of basic conditions coordinated with other major helicopter manufacturers. This format was used to present complete mission profiles representative of the intended usage for six helicopter types; i.e., observation, utility, utility/tactical assault, attack, crane, and transport. These profiles and the accompanying graphs showing load factor distribution with airspeed, altitude, and gross weight have been developed in terms of non-dimensional design parameters for application to future helicopters with improved maneuver capabilities.

The developed profiles were evaluated for authenticity in Task III. The profiles were compared to the operational data and found to be in generally good agreement in view of the differences between the operational flight load parameters and the design criteria. The profiles were further evaluated by comparison to military specifications. Differences were found to be related to practical considerations and to the differences between operational data and intended usage.

Specific mission profile segments and basic flight conditions in which high structural loads, high vibration, and/or high fatigue damage rates occur were identified in Task IV. All rotating and stationary components for which flight loads data were available were used for this purpose. Conditions uniquely critical to each type of helicopter were identified, indicating that, in general, the critical conditions were not related to the mission requirements. In most cases the critical conditions appeared to be the result of the structural design of the specific model rather than a characteristic of the helicopter type as a whole. Four maneuvers were found to be universally critical for the six types. These were found to be related to fundamental helicopter principles. The relationship of high loads, high fatigue damage rate, and high vibration was discussed, including the propensity to occur individually or simultaneously. High vibration was found to have little correlation with high loads or high fatigue damage based on the limited data available.

RECOMMENDATIONS

Presentation of helicopter operational data has improved greatly since the early efforts in the 1950's. In spite of this improvement, a great deal of interpretation was necessary for this effort. Re-editing one of the data samples into the segments of the standard profile developed in this report is recommended. This would demonstrate that the standard mission segments are conducive to editing operational data. Comparing the results of the re-edited data to those of Figures 1 and 2 would verify the distribution techniques and assignment of maneuvering portions in Task II. In addition, presentation of load factor data should be improved to allow determination of the time spent at each load factor increment and to the number of load factor peaks. Previous reports have recommended smaller increments and inclusion of data closer to the 1g level. This recommendation is reiterated and, in addition, correlation of load factor occurrence with the other flight parameters is strongly recommended.

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28. Thomas, J. C., MODEL YUH-1D STATISTICAL LOAD LEVEL SURVEY, Report 205-099-046, Bell Helicopter Company, Fort Worth, Texas, October 1963.

29. Bowan, D. W., SURVEY OF LOADS ON A BELL HU-1A HELICOPTER DURING SERVICE OPERATIONS, University of Dayton Research Institute, Contract No. FWH 228712, June 1972.

30. Spencer, J. L., MEASURED FLIGHT PROFILES FROM UH-1C, UH-1D/H, AND AH-1G HELICOPTERS OPERATING IN SOUTHEAST ASIA, Report No. 204-100-061, Bell Helicopter Co., Fort Worth, Texas, 11 November 1971.

31. Porterfield, John D., and Maloney, Paul F., EVALUATION OF HELICOPTER FLIGHT SPECTRUM DATA, Kaman Corp., USAAVLABS Technical Report 68-68, U.S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1968, AD 680280.

32. Porterfield, John D., Smyth, William A., and Maloney, Paul F., THE CORRELATION AND EVALUATION OF AH-1G, CH-54A, AND OH-6A FLIGHT SPECTRA DATA FROM SOUTHEAST ASIA OPERATIONS, Kaman Corp., USAAMRDL TR 72-52, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1972, AD 755554.

33. Graham, G. L., COMBAT OPERATIONAL FLIGHT PROFILES ON THE UH-1C, AH-1G, AND UH-1H HELICOPTERS, Bell Helicopter Co., Fort Worth, Texas, Presented at 26th Annual National Forum of American Helicopter Society, June 1970.

34. Peckham, C. G., Giessler, F. J., and Braun, J. F., A STRUCTURAL FLIGHT LOADS RECORDING PROGRAM ON CIVIL TRANSPORT HELICOPTERS, Technology Inc., Federal Aviation Agency Technical Report FAA-ADS-79, July 1966.

35. Giessler, F. J., and Braun, J. F., A HELICOPTER STRUCTURAL FLIGHT LOADS RECORDING PROGRAM, Technology Inc., Federal Aviation Agency Technical Report FAA-ADS-89, December 1966.

36. Watson, W. R., Jr., Lt. Col., and Dunham, J. R., Lt. Col., RESUME OF UNITED STATES ARMY HELICOPTER OPERATIONS IN VIETNAM, Paper No. 231 of the 24th Annual National Forum of the American Helicopter Society, May 1968.

37. Shadrick, U. W., Lt. Col., Maloney, W. R., Lt. Col., and Edwards, M. E., Maj., INTEGRATED OPERATIONS OF MARINE CORPS LIGHT, MEDIUM, AND HEAVY HELICOPTERS IN VIETNAM, Paper No. 232 of the 24th Annual National Forum of the American Helicopter Society, May 1968.

38. Brown, W. P., and Roeser, E. P., COMPARISON OF HELICOPTER COMBAT ENVIRONMENTS TO STRUCTURAL CRITERIA REQUIREMENTS, Boeing-Vertol, Naval Air Development Center, presented at the 25th Annual National Forum of the American Helicopter Society, May 1969.

APPENDIX

BIBLIOGRAPHY ABSTRACTS

1. AERONAUTICAL REQUIREMENTS, Naval Air Systems Command, AR-56, 17 February 1970.

   The U. S. Naval specification covering the static and dynamic structural design criteria and structural data requirements for helicopters. It defines the minimum requirements for flight, ground, and pilot applied loads, the loading distribution, and stress of all components.

2. CIVIL AERONAUTICS MANUALS 6, including Amendments 6-1 through 6-4, Federal Aviation Agency, 20 December 1956.

   The Federal Aviation Agency specifications for rotorcraft airworthiness. This manual contains sections on service life determination, including percentage of occurrence tables.

3. ENGINEERING DESIGN HANDBOOK, HELICOPTER, PART 3, QUALIFICATION ASSURANCE, Army Materiel Command Pamphlet 706-203, December 1971.

   This handbook is the U. S. Army guideline for helicopter engineering. Part three deals with qualification assurance. Section 8-2 presents methods of conducting a flight load survey and gives some examples of flight conditions that should be surveyed.

4. Roeser, E. P., and Flowers, J. A., SURVEY OF HELICOPTER FLIGHT-LOAD PARAMETERS, Weptask Problem Assignment No. 1-22-71, Aeronautical Structures Laboratory Report NAEC-ASL-1061, U.S. Naval Air Engineering Center, Philadelphia, Pennsylvania, 27 September 1963.

   The objective of the study was to make a field survey of the helicopter flight-load environment. It was necessary to develop and install a compact recorder system which would require a minimum of field maintenance. Recorded data were supplemented with brief pilot reports. The program was carried out with a minimum of interference to squadron operations. Recorded flight data were analyzed with the objective of determining the essential flight

parameters necessary to best describe the flight-load history. A statistical presentation of representative samples of flight data covering field use of the helicopter was made including histograms, exceedance curves, and acceleration spectra tables.

5. Crim, Almer D., and Hazen, Marlin E., NORMAL ACCELERATIONS AND OPERATING CONDITIONS ENCOUNTERED BY A HELICOPTER IN AIRMAIL OPERATIONS, Langley Aeronautical Laboratory, NACA TN 2714, National Advisory Committee for Aeronautics, Washington, D. C., June 1952.

An analysis is presented of the normal accelerations and operating conditions encountered by a single-rotor helicopter engaged in airmail operations in the vicinity of Los Angeles and its suburbs. Data were obtained for 14 months of operation, from May 1950 through June 1951, and represent 1691 flights (253 hours of flying time).

The results indicate that, for this type of operation, maneuver loads developed in routine flight are often greater than the largest gust loads. Considering the maximum positive and negative acceleration increments reached in each flight, approximately 54 percent of these maximums were due to maneuvers occurring either at takeoff or during the landing descent.

The largest en-route accelerations, due to gusts or maneuvers, are similar in magnitude to the landing-descent maneuver loads. Maximum increments recorded en route were 0.70g and -0.60g, while corresponding values for the descent were 0.60g and -0.55g.

6. Hazen, Marlin E., A STUDY OF NORMAL ACCELERATIONS AND OPERATING CONDITIONS EXPERIENCED BY HELICOPTERS IN COMMERCIAL AND MILITARY OPERATIONS, Langley Aeronautical Laboratory, NACA TN 3434, National Advisory Committee for Aeronautics, Washington, D. C., April 1955.

An analysis is presented of the normal accelerations and operating conditions encountered by two different airmail helicopters and a military pilot-training helicopter. The results, based on 4325 flights (618 hours of flying time), indicate that maneuvers are usually responsible for the relatively large accelerations encountered, whereas gusts contribute primarily to the large number of smaller accelerations and the corresponding increase in the amount of time spent in the accelerated state.

The largest maneuver loads recorded to date are increments (measured from the 1g normal-flight condition) of 1.40g and -1.25g, whereas the largest gust-acceleration increment was 0.90g.

The percentages of total flight time spent in the various flight conditions and speed ranges, as well as the acceleration time histories, are very similar for the two airmail helicopters and appear to follow a definite pattern as contrasted to the varied operating conditions of the military pilot-training helicopter.

7. Conner, Andrew B., and Ludi, LeRoy H., A SUMMARY OF OPERATING CONDITIONS EXPERIENCED BY TWO HELICOPTERS IN A COMMERCIAL AND MILITARY OPERATION, Langley Research Center, NASA TN D-251, National Aeronautics and Space Administration, Washington, D. C., April 1960.

A survey is presented of the conditions under which a helicopter engaged in commercial operations and a helicopter engaged in military operations were operated. The data, obtained with an NASA (formerly NACA) helicopter VGHN recorder, represent 2366 flights or 410 flying hours.

The results indicate that neither helicopter was operated above the maximum allowable airspeed and both helicopters spent the largest percentage of time at approximately 60 to 70 percent of the maximum design airspeed. The rates of climb and descent were varied and distributed over the entire airspeed range for both helicopters. During this survey, both helicopters made approximately six landings per flying hour. Both helicopters were operated at normal rotor rotational speeds during all flight conditions.

The center-of-gravity normal acceleration experience above a threshold of ±0.4g was more severe in the military operation than in the airmail operation.

8. Conner, Andrew B., A SUMMARY OF OPERATING CONDITIONS EXPERIENCED BY THREE MILITARY HELICOPTERS AND A MOUNTAIN-BASED COMMERCIAL HELICOPTER, Langley Research Center, NASA TN D-432, National Aeronautics and Space Administration, Washington, D. C., October 1960.

The results of a survey of the flight conditions experienced by three military helicopters engaged in simulated and actual military missions, and a commercial helicopter operated in the mountainous terrain surrounding Denver, Colorado, are presented. The data, obtained with NASA helicopter VGHN recorders, represent 813 flights or 359 flying hours, and are compared where applicable to previous survey results.

The current survey results show that none of the helicopters exceeded the maximum design airspeed. One military helicopter, used for instrument flight training, never exceeded 70 percent of its maximum design airspeed.

The rates of climb and descent utilized by the IFR training helicopter and of the mountain-based helicopter were generally narrowly distributed within all the airspeed ranges. The number of landings per hour for all four of the helicopters ranged from 1.6 to 3.3.

The turbine-engine helicopter experienced more frequent normal-acceleration increments above a threshold of ±0.4g (where g is acceleration due to gravity) than the mountain-based helicopter, but the mountain-based helicopter experienced acceleration increments of greater magnitude.

Limited rotor rotational speed time histories showed that all the helicopters were operated at normal rotor speeds during all flight conditions.

9. Truett, Bruce, et al, SURVEY OF STRAINS AND LOADS EXPERIENCED BY THE BELL H-13H, VERTOL H-21C, AND SIKORSKY H-34A HELICOPTERS DURING SERVICE OPERATION, University of Dayton Research Institute, WADD TR 60-818, Aeronautical Systems Division, Air Force Systems Command, United States Air Force, Wright-Patterson Air Force Base, Ohio, May 1961.

Two each of three helicopter models (H-13H, H-21C, and H-34A) were instrumented to yield strain and operational load information. Data were acquired during several months of service operation by U. S. Army organizations. Load and strain histories are presented in graphical and tabular form. A statistical study was undertaken to investigate sampling techniques and other statistical aspects of the program.

10. DiCarlo, Daniel J., A SUMMARY OF OPERATIONAL EXPERIENCES OF THREE LIGHT OBSERVATION HELICOPTERS AND TWO LARGE LOAD-LIFTING MILITARY HELICOPTERS, Langley Research Center, NASA TN D-4120, National Aeronautics and Space Administration, Washington, D. C., September 1967.

A survey of the operations of three different prototype light observation helicopters and of two large load-lifting helicopters, each involved in simulated military operations, was conducted with helicopter flight recorders in order to provide a basis for extending helicopter design and service life criteria. The data are representative of 3064 flights (2870 flying hours) for the light helicopters and 149 flights (125 flying hours) for the load lifters. The operating experiences are presented in terms of the time spent within different airspeed brackets, the classifiable flight conditions of climb, en route, and descent, and at different rotor rotational speeds. Normal acceleration occurrences above the incremental value of ±0.4g are also presented.

Results for this survey show that each helicopter spent a large amount of time in the upper portion of the speed range and exceeded its handbook maximum velocity for a small percentage of the total flight time. Broad variations in rates of climb and descent occurred over a wide range of airspeeds. Normal acceleration experiences reached 75 to 98 percent of the aerodynamically attainable maximum estimated for the specific flight conditions. Rotor rotational speeds were held at the normal values for most of the flight time, but a large number of values exceeded either the upper or lower redline limits.

11. Clay, Larry E., et al, UH-1F HELICOPTER FLIGHT LOADS INVESTIGATION PROGRAM, Technology Incorporated, USAAVLABS TR 66-46, U. S. [illegible], Fort Eustis, Virginia, May [illegible], AD [illegible].

To provide designers with the load spectra experienced by operational aircraft, a flight loads investigation program was performed for UH-1B aircraft under simulated combat conditions.

The operational characteristics of the UH-1B are analyzed in the 210-hour statistical sample of data compiled in this report. Parameters measured included airspeed, altitude, outside air temperature, acceleration at the aircraft center of gravity, main rotor rpm, collective stick positions, longitudinal cyclic stick position, and engine torque. Supplementary information for each flight consisted of gross weight, type of mission, and barometric pressure. An airborne oscillographic recorder system was used to obtain the data.

The data from each flight were classified as belonging to one of the following four mission segments: ascent, descent, maneuver, or steady state. By grouping and correlating the various parameters with the supplemental information provided, exceedance curves, histograms, and gust spectra were generated to provide guidelines for aircraft design.

Comparison of the gust response of the UH-1B helicopter to that of the OV-1A fixed-wing aircraft indicated that perhaps a theoretical gust factor for helicopters could be related to derived gust velocities for fixed-wing aircraft. This gust analysis was conducted by Technology Incorporated.

12. Braun, Joseph F., et al, CH-54A SKYCRANE HELICOPTER FLIGHT LOADS INVESTIGATION PROGRAM, Technology Incorporated, USAAVLABS TR 66-58, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, June 1966, AD 638364.

This report deals with the analysis of 110.4 hours of CH-54A Skycrane flight loads data. Oscillograph recorders were used to collect the parameters measured, including airspeed, altitude, vertical acceleration at center of gravity, main rotor rpm, longitudinal cyclic stick position, collective stick position, outside air temperature, torque on each engine, and gas producer rpm on each engine. Barometric pressure and takeoff-and-landing gross weight estimates were also recorded as supplemental information. The flight data were divided into four categories by mission: ascent, maneuver, descent, and steady state. The aircraft were performing their normal mission functions during the period in which the data were collected.

Time history tables, histograms, peak counts, and exceedance curves were generated from the data. As a result of this study, designers now have a limited sample of conditions experienced by four CH-54A aircraft in the field.

13. Braun, Joseph F., and Giessler, F. Joseph, CH-47A CHINOOK FLIGHT LOADS INVESTIGATION PROGRAM, Technology Incorporated, USAAVLABS TR 66-68, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, July 1966, AD 640142.

This report covers the collection and presentation of 165 hours of usable flight data for the CH-47A helicopter. The data recording system and the data processing procedure are described, and an analysis summary of the results of the flight data is presented. The flight data were recorded between 9 September 1964 and 2 December 1965. The area of operation was primarily at or adjacent to Fort Benning, Georgia. To analyze parameters according to distinct flight phases, the reduced data were separated into four mission segments: takeoff and ascent; maneuver; descent, flare, and landing; and steady state. In the form of tables, histograms, and exceedance curves, the data indicate the time flown in the mission segments and parameter ranges, and the number of parameter peaks occurring in the missions and ranges of other parameters. Exceedance curves are given for both the maneuver and the gust normal load factors.

14. Giessler, F. Joseph, and Braun, Joseph F., FLIGHT LOADS INVESTIGATION OF COMBAT ARMED AND ARMORED CH-47A HELICOPTERS OPERATING IN SOUTHEAST ASIA, Technology Incorporated, USAAVLABS TR 68-1, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, March 1968, AD 671672.

From a structural flight loads program on three armed and armored CH-47A helicopters, 207 hours of valid multichannel flight data were recorded as the helicopters operated from air bases in Southeast Asia. Data were processed and analyzed according to four distinct flight phases, termed mission segments: takeoff and ascent; maneuver; descent, flare, and landing; and steady state. Data are presented in the form of time and occurrence tables, histograms, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver and gust normal load factors and lateral and longitudinal load factors. The largest normal load factor was 1.95, which occurred at a 100-knot airspeed and with a 28,027-pound gross weight. In contrast to previous studies of cargo and transport CH-47A's whose activity was mostly under steady-state conditions, the armed CH-47A's spent more than half of their time in the maneuver mission segment and had a much more pronounced loads spectrum.

15. Giessler, F. Joseph, and Braun, Joseph F., FLIGHT LOADS INVESTIGATION OF CARGO AND TRANSPORT CH-47A HELICOPTERS OPERATING IN SOUTHEAST ASIA, Technology Incorporated, USAAVLABS TR 68-2, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, April 1968, AD 672842.

From a structural flight loads program on four CH-47A cargo and transport helicopters, 235.76 hours of valid multichannel flight data were recorded as the helicopters operated from air bases in Southeast Asia. Data were processed and analyzed according to four distinct flight phases, termed mission segments: takeoff and ascent; maneuver; descent, flare, and landing; and steady state. Data are presented in the form of time and occurrence tables, histograms, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver and gust normal load factors. The largest normal load factor was 1.628, which occurred at a 93-knot airspeed and with a 22,100-pound gross weight. In contrast to a concurrent study of armed CH-47A's whose activity was mostly under maneuvering conditions, the cargo and transport CH-47A's spent over 65 percent of their time in the steady-state mission segment.

16. Giessler, F. Joseph, et al, FLIGHT LOADS INVESTIGATION OF AH-1G HELICOPTERS OPERATING IN SOUTHEAST ASIA, Technology Incorporated, USAAVLABS TR 70-51, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, September 1970, AD 878039.

From a structural flight loads program on three AH-1G helicopters, 408.2 hours of valid multichannel flight data were recorded as the helicopters operated from bases in Southeast Asia. Data were

processed and analyzed according to four distinct flight phases, termed mission segments: takeoff and ascent; maneuver; descent, flare, and landing; and steady state. Data are presented in the form of time and occurrence tables, histograms, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver and gust normal load factors. The data are presented in two samples of 201.7 hours and 206.5 hours. These samples, identified as Sample I and Sample II respectively, were obtained consecutively. Sample I was recorded between August 1968 and April 1969, and Sample II was recorded between April 1969 and November 1969. This separate presentation is made to permit an evaluation of the validity of the 200-hour sample as an adequate data base. The differences between the two samples were minor, and the two samples were observed to be similar in their distributions of flight data.

17. Giessler, F. Joseph, et al, FLIGHT LOADS INVESTIGATION OF CH-54A HELICOPTERS OPERATING IN SOUTHEAST ASIA, Technology Incorporated, USAAVLABS TR 70-73, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1971, AD 881238.

During a structural flight loads program on six CH-54A helicopters operating in the Vietnam theater, 1048 hours of 11-channel flight data were recorded between August 1968 and February 1970. To study the adequacy of a 200-hour data sample, as well as to derive appropriate environmental loads spectra, two sets of valid data, one representing 204 hours and the second 207 hours, were processed and analyzed according to four distinct flight phases, termed mission segments: takeoff and ascent; maneuver; descent, flare, and landing; and steady state. Data are presented in the form of time and occurrence tables, histograms, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver and gust normal load factors. The analysis of the two sets of data presentations revealed that the two samples differed little and compared closely in their distribution of the flight data.

18. Johnson, Raymond B., Jr., Clay, Larry E., Myers, Ruth E., OPERATIONAL USE OF UH-1H HELICOPTERS IN SOUTHEAST ASIA, Technology Incorporated, USAAMRDL TR 73-15, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, May 1973, AD 764260.

From operational usage parameter measurements on three UH-1H helicopters, 203 hours of valid multichannel flight data were recorded while the helicopters operated from bases in Southeast Asia. Data were processed and analyzed according to four flight phases, called mission segments: ascent, maneuver, descent, and steady state. Data are presented in the form of time and occurrence tables, cumulative frequency distribution curves, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver or gust normal load factors. The data presented were recorded between September 1971 and March 1972.

19. Giessler, F. Joseph, et al, FLIGHT LOADS INVESTIGATION OF OH-6A HELICOPTERS OPERATING IN SOUTHEAST ASIA, Technology Incorporated, USAAMRDL TR 71-60, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1971, AD 738202.

From structural flight loads measurements on three OH-6A helicopters, 216 hours of usable multichannel flight data were recorded as the helicopters operated from bases in Southeast Asia. Data were processed and analyzed according to four flight phases, called mission segments: ascent, maneuver, descent, and steady state. Data are presented in the form of time and occurrence tables, histograms, and exceedance curves. These data indicate the time spent in the mission segments and parameter ranges; the number of peak parameter values occurring in the ranges of the given parameter during each of the mission segments, and in the ranges of one or more related parameters; and the time to reach or exceed given maneuver and gust normal load factors. The data presented were recorded between March and September 1970. The OH-6A's encountered more load factor peaks per hour but fewer Δn_z (incremental normal load factor) peaks above 1.0 than the heavier AH-1G's in a previous program.

20. Mongillo, A. L., Jr., and Johnson, S. M., CH-54A DESIGN AND OPERATIONAL FLIGHT LOADS STUDY, Sikorsky Aircraft Division of United Aircraft Corp., unpublished report, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

Sikorsky Aircraft has conducted an analysis and correlation study of predicted fatigue design data and operational flight loads data for crane-type helicopters. The purpose of the study was to compare operational mission profiles with a design mission profile and to provide data for use in establishing structural design criteria for future Army helicopters.

In this study, flight loads and usage data from USAAVLABS Technical Report 70-73, "Flight Investigation of CH-54A Helicopters Operating in Southeast Asia," were compared with CH-54A design data. The effects of gross weight and altitude on true airspeed were determined. Fatigue spectra were developed for six dynamic components, and fatigue lives were calculated for these components. These fatigue lives were compared with lives predicted during CH-54A design. Service histories for these components were reviewed, and it was found that none of the changes made in these components resulted from load conditions. Peak operational load parameters were compared with limit static design values. Recommendations were then developed to assist in establishing future crane helicopter fatigue design criteria.

Comparison of CH-54A operational mission profiles with the design mission profile indicated that crane operating conditions in a combat environment were generally less severe than predicted. The fatigue substantiation of the six selected components confirmed this. Extended or "unlimited" replacement times resulted for all six components.

Airspeeds above 90 knots were rarely associated with an external payload configuration. Most aircraft flight time occurred in a density altitude range of 2000 to 5000 feet. Approximately 97 percent of the measured load factor peaks occurred at gross weights at or below 29,000 pounds.

Future Army helicopter designs will benefit from improved data collection and editing techniques. Better definition of discrete ground and flight regimes is required to develop accurate mission profiles. Consideration should be given to development of a composite operational spectrum based upon a combat environment and on peacetime operation. Knowledge of peak loads and specific load parameters, such as main rotor head moment or main and tail rotor flapping angles, would yield more accurate fatigue load prediction.

21. Glass, Max E., et al, AH-1G DESIGN AND OPERATIONAL FLIGHT LOADS STUDY, Bell Helicopter Company, Fort Worth, Texas, unpublished report, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

This report compares AH-1G helicopter Southeast Asia mission profiles with the original engineering frequency-of-occurrence spectrum and the Navy AR-56 spectrum for attack helicopters. Fatigue lives calculated using the Southeast Asia profile are compared with those determined using the original frequency-of-occurrence spectrum. The development cycle of the Bell Helicopter Company Model 540 rotor system is reviewed, and the fatigue design methods used are presented. Maximum one-time occurrences measured in the Southeast Asia operational survey are compared with those specified in the AH-1G structural design criteria and those measured in structural demonstration flight tests. Recommendations are made regarding future mission surveys, the structural design criteria for attack helicopters, and the upgrading of rotor loads prediction capability.

22. Herskoyitz, A., CH-47A DESIGN AND OPERATIONAL FLIGHT LOADS STUDY, The Boeing Company, Vertol Division, Philadelphia, Pennsylvania, unpublished report, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia.

The purpose of this study was to evaluate the adequacy of current structural design criteria for future cargo and transport-type helicopters based on the design, development, and operational use of the CH-47A Chinook helicopter. It was concluded that current structural design criteria are adequate to ensure structural safety. Specifications for procurement of new helicopters should be modified to provide the most realistic mission description possible for fatigue design, with the objective of simplifying the design task.

While analyzing CH-47A operational data, several deficiencies were identified in the data acquisition and analysis process. The deficiencies can be overcome in future field survey work by cooperative advanced planning between the cognizant Army agency, the helicopter manufacturer, and the contractor responsible for data acquisition and analysis.

23. OH-6A DESIGN AND OPERATIONAL FLIGHT LOADS STUDY, Hughes Helicopters, Culver City, California, USAAMRDL TR 73-21, Eustis Directorate, U. S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, January 1974, AD775832.

A study has been conducted by Hughes Helicopters to analyze and correlate OH-6A helicopter engineering design criteria and actual operational flight load data recorded in Southeast Asia. Based on the results of the study, recommendations are made for additions and changes to improve the structural design criteria for future Army observation type helicopters. These recommendations were based on the results of four steps. First a mission profile was developed corresponding to the operational data. Step two was an evaluation of the effect of the derived spectrum on the fatigue life of main and tail rotor components. Step three was an historical synopsis and correlation of OH-6A design changes and changes in mission assignment. Step four was a comparison of maximum and minimum one-time occurrences of selected parameters between the operational data, design criteria, and values measured during engineering development tests.

24. thru 30. Not available.

31. Porterfield, John S., and Maloney, Paul F., EVALUATION OF HELICOPTER FLIGHT SPECTRUM DATA, Kaman Corp., USAAVLABS TR 68-68, U. S. Army Aviation Materiel Laboratories, Fort Eustis, Virginia, October 1968, AD 680258.

This report evaluates helicopter flight spectrum data previously recorded and published in other reports, with emphasis on the UH-1B utility, CH-47A cargo, and CH-54A load-lifting helicopters as used in the Army environment. A limited statistical analysis of the data is presented for those parameters for which sufficient data were available. The report includes a comparison of the flight-measured data with the spectrum appearing in Appendix A of Civil Aeronautics Manual 6, and with the assumed fatigue substantiation spectrum, where this was available. Discussion and evaluation of the spectrum variations that do occur, particularly as they might affect component fatigue lives, are also included.

A method for deriving an operational spectrum for the classes of helicopters evaluated is presented along with discussion of some of the considerations and judgment which play a part in the establishment of a rational, conservative spectrum for the critical components.

32. Porterfield, John D., et al, THE CORRELATION AND EVALUATION OF AH-1G, CH-54A, AND OH-6A FLIGHT SPECTRA DATA FROM SOUTHEAST ASIA OPERATIONS, Kaman Corp., USAAMRDL TR 72-56, Eustis Directorate, U.S. Army Air Mobility Research and Development Laboratory, Fort Eustis, Virginia, October 1972, AD 755554.

This report evaluates the flight spectra data for three vastly different types of helicopters flown under combat conditions in Southeast Asia: the AH-1G, a high-speed gunship; the CH-54A, a heavy-lift helicopter; and the OH-6A, a light, highly maneuverable observation helicopter. The flight spectra data for these three ships were compared to one another, to flight spectra data obtained from other helicopters, and to the spectrum shown in Appendix A of Civil Aeronautics Manual 6. The relationship to empirical fatigue substantiation spectra used to establish component service lives for these three helicopters is also shown. Evaluations and correlations of these spectra are presented: where variations occur, their probable cause and possible effects on fatigue life are discussed.

33. Graham, G. L., COMBAT OPERATIONAL FLIGHT PROFILES ON THE UH-1C, AH-1G, AND UH-1H HELICOPTERS, Bell Helicopter Co., Fort Worth, Texas, presented at 26th Annual National Forum of AHS, June 1970.

In 1965 a prototype recorder was developed and evaluated in support of a program to obtain data concerning the operational usage of each type of Bell Huey helicopter currently deployed in Vietnam. As a result, in July of 1967 nine recorders were fabricated and shipped to South Vietnam for installation in combat assault aircraft. This paper presents the results of the data obtained from this program, and compares operational flight spectrums with the predicted frequency of occurrence spectrum.

34. Peckham, C. G., et al, A STRUCTURAL FLIGHT LOADS RECORDING PROGRAM ON CIVIL TRANSPORT HELICOPTERS, Technology Incorporated, Federal Aviation Agency Technical Report FAA-ADS-79, July 1966.

A flight loads program on a transport helicopter was conducted using a Boeing-Vertol 107-II helicopter operated by New York Airways. The following parameters were measured: airspeed, altitude, vertical load factor, pitch rate, rotor rpm, and two engine torques. Calculations based on the measured parameters included the running gross weight and rate of climb. The data were grouped into mission segments of takeoff and ascent; cruise; descent, flare and landing, and hover. After the best method of data presentation was determined, the data were sorted by parameter ranges. The primary presentation is in the form of bivariate and trivariate tables showing the time spent in each data range. Some of the more significant data effects are presented as histograms. The vertical load factor and pitch rate data are presented as exceedance and probability curves.

35. Giessler, F. J., and Braun, J. F., A HELICOPTER STRUCTURAL FLIGHT LOADS RECORDING PROGRAM, Technology Incorporated, Federal Aviation Agency Technical Report FAA-ADS-89, December 1966.

A flight loads program was conducted on a Sikorsky S61N transport helicopter operated by San Francisco-Oakland Helicopter Airlines, Inc. The following parameters were measured: airspeed, altitude, longitudinal cyclic stick position, collective stick position, two engine torques, normal acceleration at center of gravity, yaw angular rate, pitch angular rate, and rpm. The rate of climb, thrust coefficient, and tip speed ratio were calculated from the measured parameters. The data were grouped into flight segments of takeoff and ascent; cruise; descent, flare and landing; and hover. The data were sorted by parameter ranges and are presented as bivariate and trivariate tables showing the time spent in each data range. Histograms present some of the more significant aspects of the data, and exceedance and probability curves depict the vertical load factor and the pitch and yaw rates.

36. Watson, W. R., Jr., Lt. Col., and Dunham, J. R., Lt. Col., RESUME OF UNITED STATES ARMY HELICOPTER IN VIETNAM, Paper No. 231 of the 24th Annual National Forum of the AHS, May 1968.

This paper addresses the following two aspects of helicopter operations in Vietnam:

PART I

A broad description of the different types of missions being flown with some data depicting the scope of the mission, frequency of occurrence, loads transported, distances involved, time of day performed, command and control techniques, and other information that assists in portraying the helicopters' usage in the total force effort.

PART II

Since most of the helicopters used in Vietnam were not designed to perform specific missions demanded by the Southeast Asia environment, recommended changes in characteristics and features in the next generation of aircraft from an operational, safety and maintainability viewpoint are described. Examples of changes are stated and suggested design criteria discussed.

37. Shadrick, U. W., Lt. Col., et al, INTEGRATED OPERATIONS OF MARINE CORPS LIGHT, MEDIUM, AND HEAVY HELICOPTERS IN VIETNAM, Paper No. 232 of the 24th Annual National Forum of the AHS, May 1968.

The objective of this paper is to present an image of the tactical use of helicopters by the Marine Corps during operations in the Republic of Vietnam. Emphasis is placed on the combat assault. In addition, the decision by the Marine Corps to arm helicopters and some future implications are covered.

38. Brown, W. P., and Roeser, E. P., COMPARISON OF HELICOPTER COMBAT ENVIRONMENTS TO STRUCTURAL CRITERIA REQUIREMENTS, Boeing-Vertol, Naval Air Development Center, presented at the 25th Annual National Form of the AHS, May 1969.

The extended use of helicopters in unforeseen combat operations has amplified the need for flight recorder programs to determine the range of mission profiles. These conditions in many cases may depart significantly from the spectra considered in the original design and development of the aircraft.

A flight recorder program was initiated to determine the operating environments of four instrumented CH-46D Sea Knight helicopters. These aircraft have seen extensive combat use by U. S. Marines in South Vietnam. In addition, flight loads were measured in critical linkages to evaluate the structural fatigue capabilities of the CH-46.

Analysis of the flight recorder data and comparison with current fatigue design profiles show that the aircraft design criteria are adequately and necessarily conservative. It is pointed out, however, that the measurements reflect only a small sample of data. Additional operational flight load strain survey programs are encouraged.